PB-230 595

WATER RESOURCES ACTIVITIES IN THE UNITED STATES. WATER SUPPLY AND DEMAND: A PRELIMINARY REPORT ON THE SUPPLY OF AND DEMAND FOR WATER IN THE UNITED STATES AS ESTIMATED FOR 1980 AND 2000

Nathaniel Wollman

Select Committee on National Water Resources,
U. S. Senate

August 1960

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

PB 230 595

86th Congress }
2d Session }

COMMITTEE PRINT NO. 32

WATER RESOURCES ACTIVITIES
IN THE
UNITED STATES

WATER SUPPLY AND DEMAND

SELECT COMMITTEE ON NATIONAL WATER RESOURCES
UNITED STATES SENATE

PURSUANT TO

S. Res. 48

EIGHTY-SIXTH CONGRESS

RECEIVE
LIBRARY
AUG 2 1968
FWPCA, OHIO BASIN REGIO
676 COLUMBIA PKWY., CINTI, O

AUGUST 1960

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

Printed for the use of the Select Committee on National Water Resources

UNITED STATES
GOVERNMENT PRINTING OFFICE
53628 WASHINGTON : 1960

SELECT COMMITTEE ON NATIONAL WATER RESOURCES

(Pursuant to S. Res. 48, 86th Cong.)

ROBERT S. KERR, Oklahoma, *Chairman*
THOMAS H. KUCHEL, California, *Vice Chairman*

DENNIS CHAVEZ, New Mexico
ALLEN J. ELLENDER, Louisiana
WARREN G. MAGNUSON, Washington
CLINTON P. ANDERSON, New Mexico
HENRY M. JACKSON, Washington
CLAIR ENGLE, California
PHILIP A. HART, Michigan
GALE W. McGEE, Wyoming
FRANK E. MOSS, Utah

MILTON R. YOUNG, North Dakota
ANDREW F. SCHOEPPEL, Kansas
FRANCIS CASE, South Dakota
THOS. E. MARTIN, Iowa
HUGH SCOTT, Pennsylvania

JAMES E. MURRAY, Montana, *Ex Officio*

PAUL McBRIDE, *Chief Clerk*
THEODORE M. SCHAD, *Staff Director*

STATEMENT BY THE CHAIRMAN

August 2, 1960.

To the Members of the Senate Select Committee on National Water Resources:

Senate Resolution 48 calls for the committee to make exhaustive studies of the extent to which water resources activities in the United States are related to the national interest, and of the extent and character of water resource activities, both governmental and nongovernmental, that will be required to provide the quantity and quality of water needed by population, agriculture, and industry between the present time and 1980, along with suitable provisions for related recreational and fish and wildlife values. In reporting out Senate Resolution 48, the Interior and Insular Affairs Committee suggested that the committee's report should respond specifically and factually to questions about water resource programs such as: (1) How much water development is needed? (2) when is it needed? (3) where is it needed? (4) what should be the pattern of water development? and (5) what levels of cost and expenditures are justifiable for future water development?

The studies of all aspects of water resources made as a part of the committee's work by the Federal agencies and others, and printed in Committee Prints Nos. 1 to 31, contain projections of needs for water and water related activities. In order to provide answers for the above-mentioned questions stated by the Interior and Insular Affairs Committee, it was necessary to put together the projections, region by region, into a water supply-demand study. In laying the groundwork for this task, the committee staff found that Resources for the Future, a privately endowed nonprofit research and study foundation, was considering a study having similar objectives. After consultation between the staffs of the committee and Resources for the Future, an agreement was made by exchange of correspondence under which Resources for the Future agreed to prepare the water supply-demand study for the committee in return for the committee's assistance in obtaining data needed for a more detailed study which Resources for the Future intends to continue for the next several years.

Resources for the Future obtained the services of Dr. Nathaniel Wollman of the Department of Economics of the University of New Mexico to undertake the water-supply-demand study and prepare a report thereon for the committee. Dr. Wollman has taken the basic projections and information furnished by the Federal agencies, and has developed tentative balance sheets on water supply and demand for each of the 22 regions into which the contiguous part of the United States was divided for the purposes of this study. The study was not extended to Alaska and Hawaii because the water resources problems of those two new States are not physically related to the problems of the contiguous part of the United States. Furthermore, data is not available in sufficient detail on water resources of the new States to permit water supply-demand reports to be developed within the time schedule of the committee. General reports on water resources problems of Alaska and Hawaii have been published as Committee Prints Nos. 19 and 20.

The report shows projections of future demands for water in all of the regions, for all purposes, and relates them to present supplies and supplies that can potentially be developed by storage. Basic water problems are related to provision of the proper quantity and quality of water in places needed at the times needed. The report therefore deals with the basic physical problems of providing necessary facilities for storage and treatment of water, quantity being controlled by storage and quality being controlled by treatment. The report develops relationships between the amount of treatment and the storage required to meet needs in 1980 and 2000, and lays out several broad potential programs for meeting the Nation's needs through either a minimum storage program, a minimum treatment program, or through a minimum economic cost program.

The report shows very clearly the great economic advantages that could be obtained by more complete treatment of the wastes that are discharged into our streams. It indicates needs for reservoir storage under the assumptions chosen for the study ranging from 229 million acre-feet in 1980, under a minimum storage program, to 315 million acre-feet under a minimum cost program. These requirements would be in addition to present storage reservoir capacity of 278 million acre-feet.

It should be kept in mind that this is a theoretical study, based on projections of needs developed without consideration of limiting factors, such as costs, alternative uses of water, or potential interregional shifts of water use. It is likely that a study prepared under different assumptions would develop different estimates of storage and treatment required, although general relationships along the lines of those shown in this report would probably prevail.

From the projections made for the committee and the report made by Resources for the Future, it is clear that a water resource development task of great magnitude lies ahead of the Nation. This report will be of great value in charting a future course, and it will be of such interest to the members of the committee, to other Senators, and to all who are interested in water resources development in the future, that I am having it printed as the last of our series of committee prints covering all water resources activities in the United States.

Rob't S. Kerr
Chairman, Select Committee on
National Water Resources.

COMMUNICATIONS

July 30, 1959.

Dr. R. G. Gustavson,
President, Resources for the Future, Inc., Washington, D.C.

Dear Dr. Gustavson: As a part of the work of the Senate Select Committee on National Water Resources, created under the authority of Senate Resolution 48, 86th Congress, a report covering water supply and demand in all of the river basins and zones in the United States between now and 1980 must be prepared. Through informal discussions and meetings between members of your staff and of the staff of this committee, we have found that Resources for the Future already has begun a more detailed study of somewhat the same nature.

Accordingly, I am writing to propose that this committee and Resources for the Future agree to cooperate in carrying out this work as follows:

1. Your foundation will prepare a report for the committee on supply-demand relations for water in the various river basins and zones in the United States.
2. The report should relate summarized tables of estimated water withdrawal and use in each river basin or zone, at present and estimated for 1980, to potential means of supply, giving the estimated costs thereof.
3. The report should be framed in such manner as to provide background which will be helpful in answering questions such as:
    - (*a*) How much water development is needed?
    - (*b*) When is it needed?
    - (*c*) Where is it needed?
    - (*d*) What should be the physical pattern of water development?
    - (*e*) In general, what levels of cost and expenditures are justifiable for future water development?

It is hoped also that the report will be helpful to the committee in developing guides as to the amounts of water required for various levels of population and economic activity, and as to the economic limits of water development in each of the basins and zones.

The foundation will provide the committee with a preliminary report by not later than January 1, 1960, assuming that data agreed upon jointly by the foundation and the committee staff is furnished by cooperating Federal agencies in sufficient time prior to this date to enable the requested information and analyses to be completed. The foundation will work with the committee after the completion of the report through July 1, 1960, in making necessary refinements and in assisting the committee staff in presenting and interpreting the report to the committee.

In return the committee will assist the foundation in obtaining necessary basic data and material from Federal agencies and elsewhere for the preliminary report as well as for the more detailed final report and it will make its staff and its consultants available to the foundation for consultation with regard to the study. It is understood that all data and estimates compiled for the committee by Federal agencies, committee staff, Resources for the Future or others in connection with these studies may be utilized in the foundation's own more detailed water supply-demand study, which may be considered for publication by Resources for the Future after the committee has made its report in January 1961. If such a publication is issued by Resources for the Future, appropriate credit will be given to those who developed the data.

The staff of Resources for the Future will work with the Federal agencies to assure cooordination of the data prepared by the several agencies involved and will work with the committee staff as required in the presentation and interpretation of the report to the committee.

No transfer of money will be made under this agreement, although if necessary, the committee may wish to engage the services of consultants and junior professional and clerical staff on a temporary basis to work with Resources for the Future, if necessary to expedite the progress of the study, or to help compile the data submitted by the Federal agencies for inclusion in the report to the committee. Appropriate arrangements for such employment may be made in accordance with the rules of the Senate for paying expenses of persons engaged in working for the committee.

I would appreciate hearing from you at an early date in confirmation of this agreement.

Sincerely yours,

ROB'T S. KERR, *Chairman.*

RESOURCES FOR THE FUTURE, INC.,
Washington, D. C., August 7, 1959.

Senator ROBERT S. KERR,
Chairman, Senate Select Committee on National Water Resources,
New Senate Office Building, Washington, D.C.

DEAR SENATOR KERR: The arrangement proposed in your letter of July 30 is satisfactory to Resources for the Future. As a public service organization, we welcome the opportunity to be of help to your committee. Moreover, through the cooperative endeavor which you propose, it should be possible for Resources for the Future to eventually publish a report which will provide an unusually comprehensive analysis of the water supply-demand outlook in the United States. Our report should be greatly strengthened because we will be able to use the data compiled for the committee.

The time schedule for preparation of the report for your committee is very brief. Accordingly, I'd like to stress the importance of having the data to be provided by the Federal agencies prior to November 1, 1959.

We are looking forward to a mutually advantageous working relationship with your committee.

Sincerely yours,

R. G. GUSTAVSON, *President.*

RESOURCES FOR THE FUTURE, INC.,
Washington, D.C., July 29, 1960.

Hon. ROBERT S. KERR,
U.S. Senate, Washington, D.C.

DEAR SENATOR KERR: Accompanying this letter are two copies of a report entitled, "The Supply of and Demand for Water" by Dr. Nathaniel Wollman, who for the past year has been a temporary member of the Resources for the Future research staff. This report has been prepared in accordance with the understanding set fourth in your exchange of correspondence with Dr. R. G. Gustavson, dated July 30 and August 7, 1959. The report is the result of the successful cooperative arrangements worked out by your Senate select committee staff between the Federal agencies and Resources for the Future and a credit to the individuals who contributed to the endeavor.

The report illuminates the nature and size of the task confronting the Nation in developing and managing its water resources. It confirms the widely held view that in the arid and semiarid West new sources of low cost water supplies must be provided if the population and economic growth now anticipated are to occur in combination with the dedication of a major portion of the region's water supplies to irrigated agriculture It indicates that in the more densely populated, industrialized areas, the maintenance of water quality consistent with the demands of a prosperous urban society constitutes the most serious water problem. Probably more important than either of these, the report gives us a better understanding of the approximate time schedule we should be prepared to meet in dealing with the problems that lie ahead. We have a better idea where we stand today and, while we work toward the targets implicit in the report for 1980 and 2000, we have the opportunity of refining our assessment of future prospects in the light of the many unforeseeable changes that will occur before those dates are reached.

The unique contribution of the report is the advance it makes toward a satisfactory framework for the analysis of water supply-demand relationships. Such a framework is urgently needed as water moves into the realm of "economic goods." The difficulties of combining for a region such widely differing kinds of demands as waste carrying and domestic use and relating demands to a variable supply have heretofore been insurmountable. No previous effort has made so much progress toward a solution of this problem. The prospects now are that we shall have a suitable structure for water supply-demand analysis and that data collection and study can now be carried forward more effectively.

With the foregoing in mind it is important to recognize that the task is not finished and for this reason the report is designated as preliminary. Accordingly, Resources for the Future intends to support continued research on this problem under Dr. Wollman's direction at the University of New Mexico, where he is resuming his post of professor of economics. We hope that the excellent cooperation of the Federal agencies which have contributed so much to the progress of the study so far will be continued as the work proceeds.

I wish to take this opportunity to express our thanks to the committee, to members of the committee's staff, and to Federal agency personnel for the contribution each made to the completion of this report. All of us, I believe, owe a special debt of gratitude to Dr. Wollman. The confidence with which he undertook and pursued what appeared to be an impossible task, the ingenuity he displayed in handling the many complexities involved, the friendly relations he established with all concerned, and the long hours he devoted to the study, command the utmost respect and admiration of everyone.

Sincerely,

JOSEPH L. FISHER,
President and Executive Director.

CONTENTS

Page
Statement by the chairman III
Communications V
Preface XIII
List of contributors XVI
Part I. Introduction and summary 1
  Introduction 1
  The analytical model 2
  The findings 6
  Conclusions 12
Part II. The supply of and demand for water: A method of comprehensive analysis 14
  Objectives of the study 14
  Method of analysis 15
  A few definitions 15
  The geographic unit: 22 water resource regions 15
  Projecting water use 16
  The special case of waste dilution 20
  The physical supply of water 22
  The costs of storage 23
  Integration of supply and demand: Physical 25
  Integration of demand and supply: Economic 30
  Limitations and qualifications 32
Part III. The results 35
  Introduction 35
  Projections of population and production 35
  Projected changes in the demand for water: Withdrawals 38
  Projected changes in the demand for water: Losses 42
  Projected changes in the demand for water: Flows 46
  Projected uses and available runoff 47
  Measures of supply: Physical and cost measures 50
  Costs of a national water resource program 64
  Costs of alternative water resource programs 67
  The burden of a water resource program: Some comparative measures 70
  Impact on specific regions 72
Part IV. Regional water supply and projected uses 77
Appendix—Calculated risk 129

LIST OF TABLES

1. Summary: Minimum storage program, 1980 8
2. Summary: Minimum storage program, 2000 8
3. Summary: Minimum cost program, 1980 9
4. Summary: Minimum cost program, 2000 9
5. Summary: Minimum treatment program, 1980 10
6. Summary: Minimum treatment program, 2000 10
7. Five western regions: Losses and sustained flows, 1980 and 2000 12
8. Total population, continental United States, water resource regions, 1950, 1960, 1980, and 2000 35
9. Urban population, water resource regions, 1950, 1960, 1980, and 2000 36
10. Selected economic measures, 1954, 1960, 1980, and 2000 37
11. Indexes of production used to derive estimates of water use 38
12. Withdrawal uses: Total withdrawals, 1954 39
13. Withdrawal uses: Total withdrawals, 1980 40

	Page
14. Withdrawal uses: Total withdrawals, 2000	40
15. Losses: Withdrawal uses, 1954	42
16. Losses: Withdrawal uses, 1980	43
17. Losses: Withdrawal uses, 2000	43
18. Actual versus computed irrigation losses, western regions, 1954	43
19. Losses: Eastern irrigation, western irrigation, 1954 and 2000	44
20. All losses: Withdrawal uses, gross land treatment and structure losses, and fish and wildlife, 1954	44
21. All losses: Withdrawal uses and increase over 1954 for land treatment and structures and fish and wildlife habitat, 1980	45
22. All losses: Withdrawal uses and increase over 1954 for land treatment and structures and fish and wildlife habitat, 2000	45
23. Estimated generation of hydroelectric power by utilities, based on average water conditions (million kilowatt-hours for 1954; billion kilowatt-hours for 1980 and 2000)	47
24. Hydroelectric water requirements, 1954, 1980, and 2000	47
25. Sport fishing habitat: Flows, 1954, 1980, 2000	47
26. Fresh water navigation flow requirements, 1959, 1980, 2000	47
27. Waste dilution flows, medium, 1980, to yield a dissolved oxygen content of 4 milligrams per liter	48
28. Waste dilution flows, medium, 2000, to yield a dissolved oxygen content of 4 milligrams per liter	48
29. Projected losses, supply available 95 percent of time under present regulation, average supply	49
30. Minimum streamflow requirements plus losses, to yield 4 milligrams per liter, 1980 and 2000	49
31. Degree of freedom in waste treatment storage combinations, 1980 and 2000	50
32. Present supply of water available	51
33. Storage required to produce selected dependable flows	51
34. Storage required for undepleted flows, selected regions	52
35. Median depth of reservoirs and loss by evaporation	52
36. Mean velocity of low flows and average stream length by water resource regions	52
37. Percentage distribution of reservoirs by size class, 1954	57
38. Total storage required and percentage distribution of total required capacity as modified, 1980 and 2000, size class	58
39. Percentage distribution of reservoir capacity by physiographic region	58
40. Costs of storage per acre-foot by size class of reservoir and physiographic region	58
41. Estimated cumulative capacity and annual costs of storage distributed by region and size class	62
42. Estimated cumulative minimum flow net of reservoir losses and cumulative annual costs, distributed by size class and region	63
43. Total required flows: Losses plus waste dilution, 1980	64
44. Total required flows: Losses plus waste dilution, 2000	65
45. Collection costs plus treatment costs: 1980	65
46. Collection costs plus treatment costs: 2000	66
47. Quantity of storage by type of program, 1980 and 2000	68
48. Quantity of flow, by type of program, 1980 and 2000	69
49. Annual costs of storage by type of program, 1980 and 2000	69
50. Annual costs of collection and treatment, by type of program, 1980 and 2000	69
51. Annual total costs of collection, treatment and storage by type of program, 1980 and 2000	69
52A–52W. Withdrawals, losses and flows by water resource region, 1954, 1980, and 2000	79–122
53A, 53B. Distribution of required flow by uses (withdrawal losses, onsite losses, and waste dilution; minimum cost program) for 1980 and 2000	124
54A, 54B. Ratio of maximum obtainable supply to minimum flow requirements for 1980 and 2000	124

Appendix I

A. Regional supplies that can be made available from storage for indicated percent of time	129–130
B. Storage requirements to yield minimum flows for the minimum cost program, 1980, 100 percent and 95 percent of the time	130

LIST OF CHARTS

Page
1. Curves showing average cost of reservoirs for water storage 60
2. Average cost of water storage reservoirs constructed by Bureau of Reclamation based on 1959 prices 61
3. Investment in collection and treatment and storage facilities for United States 1954–2000. Minimum cost program, dissolved oxygen content of 4 milligrams per liter 73
4.A–4V. Flow storage relationships, projected losses and waste dilution flow requirements, 1980 and 2000 78–120
5. Ratio of population growth by water resource region to average population growth of continental United States 123
6. Percentage distribution of required flow among losses and waste dilution, 1980 125
7. Ratio of maximum obtainable supply to minimum flow requirement, 1980 and 2000 127

LIST OF MAPS

1. Water resource regions XVIII
2. Average ratio of phosphorus: Dissolved solids in streams by water resource regions 53
3. Average ratio of nitrogen: Dissolved solids in streams by water resource regions 54
4. Average ratio of chloride: Dissolved solids in streams by water resource regions 55
5. Approximate mean monthly temperature of water from surface sources for July and August 56
6. Map to accompany reservoir cost curves 59

PREFACE

In the summer of 1958 Resources for the Future began to explore the possibility of a study of the supply of and demand for water in the United States. Several months later, after the Select Committee on National Water Resources was formed to carry on a similar investigation, it seemed desirable to join forces and eliminate duplicate activity. Only one serious difference in objectives separated Resources for the Future from the select committee: the matter of timing. The select committee needed a job done quickly, whereas RFF had a longer time schedule in mind. It was decided, therefore, that in exchange for the assistance of the select committee in procuring data from the Federal establishment, Resources for the Future would provide the select committee with a preliminary report on the supply of and demand for water.

By this arrangement Resources for the Future gained access to talents and sources of information that otherwise would have been unavailable. The Federal Government is a repository of many skills, insights, and information; without the work contributed by specialists in various agencies this report could not have been written now or, perhaps, ever. To these people, for their help in formulating the study and for the wealth of data that they supplied, Resources for the Future acknowledges a great debt.

The study is equally indebted to the assistance rendered by the chairman of the select committee, Senator Robert S. Kerr, and the staff director, Theodore M. Schad. It was clear that a nonpolitical investigation in an area filled with politics was wanted. The study was to be objective, scientific and, within the limits of time and manpower, comprehensive. Even before Resources for the Future entered the picture, written communications between Senator Kerr and agency heads along with conferences organized by Mr. Schad had gotten Federal activity underway. Afterwards, by conference, letter, and telephone, Mr. Schad saw to it that a steady stream of material was being produced. W. G. Hoyt, consultant to the select committee, found that his services were also in demand as consultant and adviser to the author of this report. It should not be inferred, however, that in rendering their services to Resources for the Future, the staff or members of the select committee determined the content of the report or any of its conclusions.

Government publications often present an anonymous face to the public because of the fact that the work of a number of people goes into a report. In the next section, "Contributors," a list of the hydrologists, engineers, agricultural economists, geologists, economists, statisticians, and other scientists who participated in the overall project is given. The author would like here to offer special thanks to several participants because of the extra burdens they carried, even though in singling out particular people one always faces the danger that someone has been inadvertently omitted.

Roy E. Oltman of the U.S. Geological Survey not only was one of a group who prepared basic hydrologic data for the report, but was also the person to whom many questions were addressed regarding various phases of the project and who carried out a number of supplementary studies as new questions arose. Howard Cook of the Corps of Engineers not only prepared the maps and curves that made it possible to construct schedules of the costs of storage for each region but gave generously of his time in helping formulate research objectives and the manner in which they could be successfully pursued. Melvin Scheidt of the U.S. Public Health Service not only served in an editorial and liaison capacity within PHS in the preparation of several reports with the collaboration of his colleagues, but performed a similar function in connection with the investigation of waste dilution requirements carried on by George Reid, Director of the Bureau of Water Resources Research, University of Oklahoma. Last, but hardly least, without the pioneering work of Professor Reid in developing a method for estimating waste dilution requirements for a water resource region and the amount of streamflow needed to maintain water quality, it would not have been possible to follow the method of analysis that was adopted for the study.

The author also owes a great deal to his colleagues at Resources for the Future. He is indebted to John Krutilla for the shower of sparks struck off throughout a year of close association. Vera Eliasberg not only prepared part IV of this report, but oversaw the preparation of Resources for the Future's contributions to the population projections contained in Committee Print No. 5, and served as critic and reviewer of the material presented in this study. The author is especially indebted to Irving K. Fox, director of the water resources program of Resources for the Future (and recently also the associate director of Resources for the Future), under whose general guidance the study was carried out.

Among others at Resources for the Future, Erna Peters had major responsibility for statistical computations and preparation of most of the tables. Doris Stell supervised the typing of the manuscript and reproduction of the tables, and generally shepherded the manuscript to completion. Statistical clerks who worked on the tables were Peter Dyer, Richard Munske, Terry Maddock, and Kathy Dolfis.

In crediting the assistance rendered by all who have been named as well as by many others, it should be pointed out that the final draft had to be prepared by the author without benefit of review. In correcting the earlier draft a number of new mistakes could easily have been substituted for old; hence the author is solely responsible for any errors that may be found.

Only a part of the Federal research effort stimulated by the select committee went into subjects designed for ultimate incorporation into this report. The other part dealt with matters of agency interest and policy and technical questions that only indirectly bore on the measurements of supply and demand. However, of the part that was concerned with supply and demand, more material was prepared than could be included in this study. It is because much yet remains to be done that this has been described as a "preliminary report."

Most of the material on which this study is based has appeared in separate form as a committee print. It is expected that the list of prints will be filled out to include material that now exists only in manuscript form.

The following are the separate studies that have served as the basis for this report:

Committee Print No. 3, "National Water Resources and Problems," Geological Survey.

Committee Print No. 5, "Population Projections and Economic Assumptions," Committee Staff, Bureau of the Census, and Resources for the Future.

Committee Print No. 7, "Future Water Requirements for Municipal Use," Public Health Service.

Committee Print No. 8, "Future Water Requirements of Principal Water Using Industries," Business and Defense Services Administration and the Bureau of Mines.

Committee Print No. 9, "Pollution Abatement," Public Health Service.

Federal Power Commission report in Committee Print No. 10, with supplementary unpublished materials, "Electric Power in Relation to the Nation's Water Resources."

Committee Print No. 11, "Future Needs for Navigation," Corps of Engineers.

Committee Print No. 12, "Land and Water Potentials and Future Requirements for Water," Department of Agriculture.

Committee Print No. 13, "Estimated Requirements for Agricultural Purposes and Their Effects on Water Supplies," Department of Agriculture.

Committee Print No. 14, "Future Needs for Reclamation in the Western States," Bureau of Reclamation.

Committee Print No. 17, "Water Recreation Needs in the United States, 1960–2000," National Park Service.

Committee Print No. 18, "Fish and Wildlife and Water Resources," Fish and Wildlife Service.

Committee Print No. 29, "Methods of Estimating Water Requirements for Pollution Abatement as a Supplemental Measure for Control of Water Quality in Rivers," by George Reid.

In addition to what has been already published or may be published, other material was supplied: precipitation and water loss by the Weather Bureau, water consumed by farm animals by the Department of Agriculture, various streamflow characteristics by the Geological Survey, costs of storage and conveyance of water by the Bureau of Reclamation, costs of storage and physiographic zones by the Corps of Engineers, a division of the projected output of chemicals into organic and inorganic by the Business and Defense Services Administration, and an estimate of water losses attributable to land treatment and structures already completed.

A brief examination of the committee prints that have already appeared will suffice to show how much material still remains to be analyzed. A few examples of what still remains to be done are in order.

The Bureau of Reclamation's report on "Future Needs for Reclamation in the Western States" was received too late to incorporate its estimates of water use into the aggregates developed for the model, as was also the case with the report on recreational water needs prepared by the National Park Service. It is expected, however, that in the amplification by "Resources for the Future" of this supply and demand study, it will be possible to construct revised models of water use that reflect the Bureau of Reclamation and National Park Service reports. Furthermore, the reason for differences between Bureau of Reclamation and U.S. Department of Agriculture estimates of prospective irrigated acreage must be explored to see whether alternative (as distinct from revised) models of water use are needed.

A number of the prints contain estimates of water use for two or three alternative projections of population and economic activity. The implications of growth rates higher or lower than implied by our medium estimates should be studied.

The report on industrial water use of the Business and Defense Services Administration, Department of Commerce (Committee Print No. 8), was prepared under the direction of Mr. Walter Picton, Director, Water and Sewerage Industry and Utilities Division. He was instrumental in including labor requirements along with estimates of output and water use, making possible some comparison among implied changes in population, labor force, and selected labor force requirements. By securing estimates of labor force requirements for other types of employment included in our study, a test of internal consistency can be applied.

Another loose end discernible in several committee prints is information included for 37 metropolitan areas. When the overall project was initiated, it could not be foretold that a means of analyzing the impact of pollution on a regionwide basis would be successfully developed. For this reason, as well as for the fact that regionwide figures were likely to conceal important intraregional differences, it was planned to study water supply and demand relationships at 37 representative metropolitan points. In order to complete this phase of the project a division of each region into subordinate parts is required. When this is done, and the location and characteristics of reservoir sites established, it will also be possible to estimate the probable amount of intraregional water conveyance and conveyance cost. These facts will also enable biologists of the Fish and Wildlife Service to judge the quality of sport fishery habitat provided by reservoirs and the degree of substitutability that can be expected between reservoirs and flowing streams as fish habitat.

There are still other tasks. For example, nothing so far has been said about the economic problems of water use in regions of prospective water shortage. A major investigation that yet remains is examination of (1) the way in which water is likely to be allocated among competing uses, (2) the resulting implied interregional shifts in population and economic activity, and (3) the implied effects on regional and national gross product and incomes. When this has been done it will then be possible to construct models of water use based upon different regional projections of population and economic activity and to ascertain the effects of such redistribution upon aggregate costs of a national water resource program.

CONTRIBUTORS TO STUDIES UTILIZED IN PREPARING THIS REPORT

The report on "Land and Water Potentials and Future Requirements" was prepared in the U.S. Department of Agriculture under the direction of a water resource review group consisting of:

Homer G. Lyon, Jr., Office of the Secretary, Chairman.
Edward C. Crafts, Forest Service.
Edward F. Mynatt, Office of the General Counsel.
Harry A. Steele, Agricultural Research Service.
Gladwin E. Young, Soil Conservation Service.
L. M. Adams, Office of the General Counsel.

The following work group was given the responsibility for preparing the report:

Harry A. Steele, Agricultural Research Service, Chairman.
Elco L. Greenshields, Agricultural Research Service.
Tyler H. Quackenbush, Soil Conservation Service.
Henry L. Lobenstein, Forest Service.
Talcott W. Edminster, Agricultural Research Service.
Nathan M. Koffsky, Agricultural Marketing Service.
Wilhelm Anderson, Foreign Agricultural Service.

This report is based on advice, consultation, and previous work of many people in the Department of Agriculture. Special acknowledgment should be made of the contribution of the following:

Agricultural Research Service: James R. Anderson, Glen T. Barton, Donald D. Durost, Willis G. Eichberger, William A. Green, Donald B. Ibach, Marvin E. Jensen, W. A. Raney, James Vermeer, and Hugh H. Wooten.
Agricultural Marketing Service: Carroll Downey.
Soil Conservation Service: Roy D. Hockensmith, Paul H. Montgomery, Harold O. Ogrosky.
Forest Service: George F. Burks, H. R. Josephson, David B. King, Warren Murphy, James C. Rettie.

The report on "Estimated Water Requirements for Agricultural Purposes and Their Effect on Water Supplies in the Years 1980 and 2000" was prepared in the U.S. Department of Agriculture under the direction of Gladwin Young, Deputy Administrator, Soil Conservation Service and H. O. Ogrosky, Chief, Hydrology Branch, Engineering Division, Soil Conservation Service. Contributors were:

Agricultural Research Service: D. L. Brakensiek, Karl Gertel, H. N. Holtan, M. L. Weinberger.
Forest Service: Henry L. Lobenstein, Harold F. Morey, Warren T. Murphy, Walter Schipull, Richard W. Wilke.
Soil Conservation Service: R. G. Andrews, John W. Barnard, W. D. Cratty, H. J. Ferris, E. C. Ford, Alfonso Geiger, Frank Harper, Melvin Kleen, Neil Lane, William Sammons, Miss Dorothy Zens.

A report on "Future Water Requirements of the Principal Water-Using Industries" was prepared in the U.S. Department of Commerce under the direction of Walter L. Picton, Director, Water and Sewerage Industry and Utilities Division, assisted by Konstantine L. Kollar, industrial specialist. The report was edited by George C. Lovell. Business and Defense Services Administration contributors were:

Iron and Steel Division: Jacob Levin, Chief, Program and Analysis Branch.
Chemical and Rubber Division: T. Allan Davis, Chief, Plastics Branch.
Forest Products Division: W. LeRoy Neubrech, Assistant Director for Pulp and Paper Board; assisted by John J. Bartosiewicz, John R. Mutzabaugh.

Containers and Packaging Division: Osker C. Reynolds, Chief, Materials Service Branch.
Food Industries Division: Shandon D. Knape.
Aluminum and Magnesium Division: John H. Styer, Chief, Products and Facilities Branch.
Copper Division: Ewing J. Talbert, Chief, Program and Requirements Branch, assisted by John C. Nesbitt

Bureau of the Census contributors were: Maxwell J. Conklin, Chief, Industry Division; William Karr, Chief Materials and Data Analysis Branch; and John Gottsegen, Chief, Commodities and Materials Data Branch.

Contributors from the U.S. Corps of Engineers, for its reports to the Senate select committee and materials prepared for Resources for the Future, were: Carter Page, Howard Cook, N. A. Back, Eber J. Riley, and Albert D. Gallucci.

The following staff members of the U.S. Federal Power Commission were of assistance in preparing material for Resources for the Future:

Francis L. Adams, Chief, Bureau of Power; Edgar T. Hughes, Chief, Division of Electric Resources and Requirements; Norman C. Nelson, Head, Section of Power Requirements and Supply; Arthur F. Proffit, Section of Power Requirements and Supply; Frank L. Weaver, Chief, Division of River Basins; William A. Liddell, Head, Section of Reports and Special Studies; and George G. Adkins and Neal C. Jennings of the Section of Reports and Special Studies.

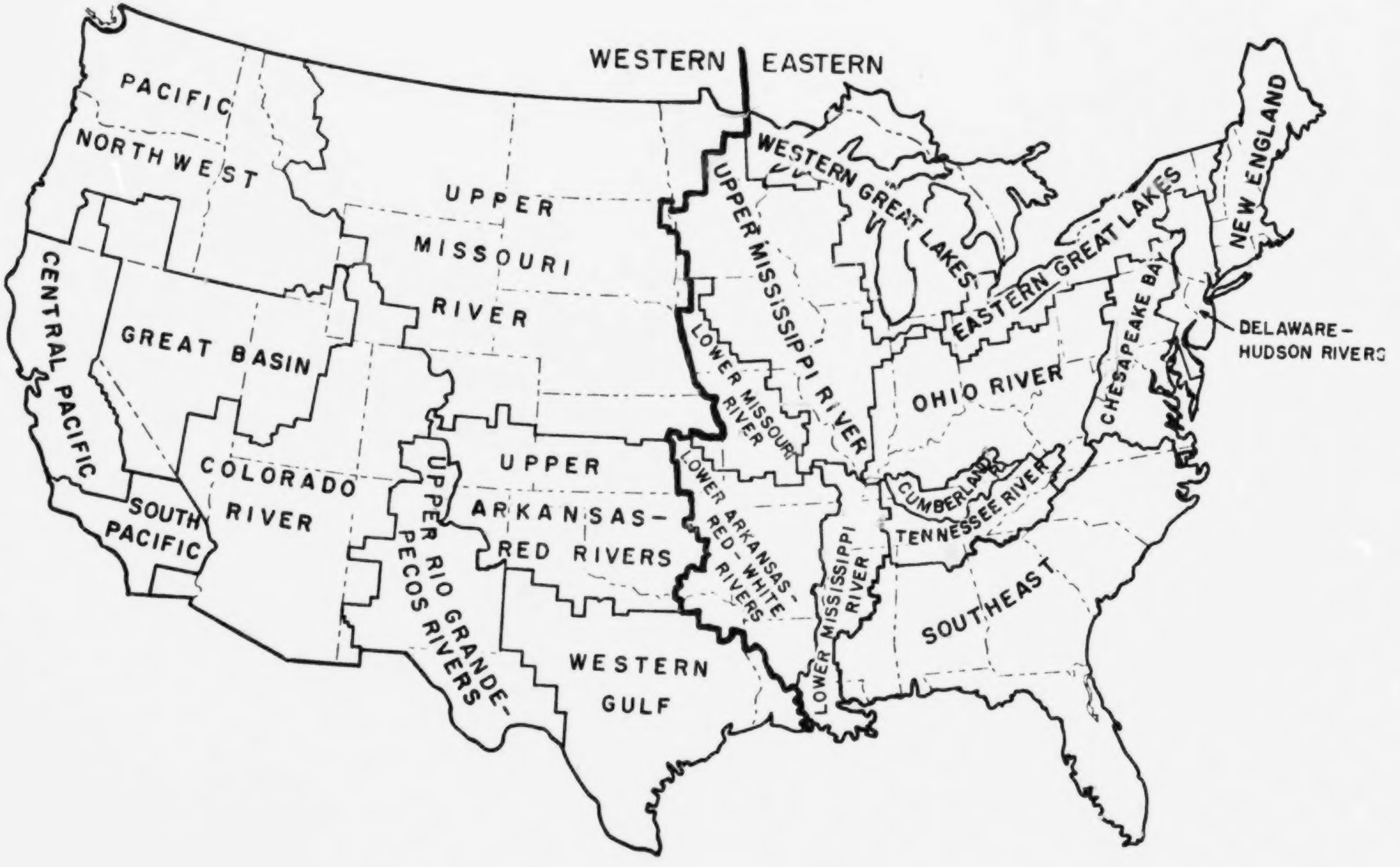
Contributors from the U.S. Department of Health, Education, and Welfare, for its reports to the Senate select committee and materials prepared for Resources for the Future included: Melvin E. Scheidt, Sidney H. Green, Kenneth H. Jenkins, Keith S. Krause, and George Reid, of the University of Oklahoma, Consultant to the Public Health Service.

Those who worked on the Senate select committee reports from the U.S. Department of the Interior were:

National Park Service: Robert W. Ludden, George W. Olcott, E. W. Perkins.
Bureau of Sport Fisheries and Wildlife: Yates M. Barber, Willis King, James T. McBroom, Carl F. Stutzman.
Bureau of Commercial Fisheries: John R. Clark, John B. Glude, John I. Hodges.
Geological Survey: Luna B. Leopold, Kenneth A. MacKichan, Glennon N. Mesnier, Roy E. Oltman, Frank H. Rainwater, Thomas W. Robinson, Horace G. Thomasson.
Bureau of Mines: Paul M. Buttermore, Leon W. Dupuy, Robert T. MacMillan, Forrest T. Moyer, W. H. Young.
Bureau of Reclamation: A. O. Babb, J. T. Casey, David Flipse, I. B. Kirkwood, J. K. Lee, Charles LeMoyne, Jr., D. V. McCarthy, H. R. McDonald, N. H. Moore, D. L. Roberts, K. B. Schroeder, E. L. Struwe, I. A. Watson.
Technical Review Staff: Lawrence Stevens, Moris Burge.

Map 1

·WATER RESOURCE REGIONS·


WESTERN
EASTERN
PACIFIC NORTHWEST
UPPER MISSOURI RIVER
CENTRAL PACIFIC
GREAT BASIN
COLORADO RIVER
SOUTH PACIFIC
UPPER RIO GRANDE-PECOS RIVERS
UPPER ARKANSAS-RED RIVERS
WESTERN GULF
WESTERN GREAT LAKES
UPPER MISSISSIPPI RIVER
LOWER MISSOURI RIVER
LOWER ARKANSAS-RED-WHITE RIVERS
LOWER MISSISSIPPI RIVER
EASTERN GREAT LAKES
NEW ENGLAND
CHESAPEAKE BAY
DELAWARE-HUDSON RIVERS
OHIO RIVER
CUMBERLAND
TENNESSEE RIVER
SOUTHEAST

A PRELIMINARY REPORT ON THE SUPPLY OF AND DEMAND FOR WATER IN THE UNITED STATES AS ESTIMATED FOR 1980 AND 2000

(By Nathaniel Wollman)

PART I. INTRODUCTION AND SUMMARY

This is a report on the Nation's prospective supply of and demand for water in 1980 and 2000, prepared for the Senate Select Committee on National Water Resources. It is based upon data specially prepared for the select committee by various Federal agencies as well as upon materials collected by these agencies under their permanent research programs. The report is in four parts. Part I contains a brief summary of the nature of the study, its findings, and major conclusions implied by the findings. Part II describes the methods used in making the study. Part III contains the overall results summarized for the entire country by water resource regions. Part IV gives detail in the form of tables and charts for each of the water resource regions. Data and conclusions are limited to the continental United States. This does not presume that Alaska and Hawaii have no water problems but only that their supplies are physically independent and that substitution of demand for their water by demand elsewhere is quite limited.

Introduction

The United States faces a number of serious water problems whose immediacy and gravity vary from region to region. In some areas they could become quite painful. Although the restraining effects of a limited water supply will soon become more noticeable in various parts of the country, the regions in which shortage will be severe have, for the most part, been aware of the fact for some time.

The impending deterioration of our streams and rivers is perhaps the most striking of our findings. Unless the country is ready to cope with water pollution on a far greater scale than at present, it appears that many streams will become putrescent and rivers open sewers. But the problem of environmental sanitation is nothing new. Having rid our city streets of garbage and human and animal wastes, we must now do the same for our rivers.

The report indicates that the status of water in our economic system is rapidly changing. Once water could be regarded as a free good—only pipes, pumps, and treatment plants cost money; water was free for the taking. This view seems destined to disappear from the Eastern scene as it did from the West some time ago.

Historical data on water demand are quite scanty. In retrospect, however, it is likely that the economy has experienced a series of discontinuous leaps in water use, each jump moving it to a higher plateau. The more recent of these jumps suddenly have made many people aware of the fact that the Nation's water supply is limited not only in the Southwest, but elsewhere as well. And while the country is in no imminent danger of running out of water, no longer is it in the enviable position of having enough water at all times for all conceivable uses. In other words, water is quickly moving into the realm of economic goods.

This situation can be attributed in large part to the growth of population and industry. But a major factor is that water-using activities have been growing more rapidly than the economy as a whole. Irrigated lands amounted to about 20.5 million acres in 1944;[1] by 1958 the figure had risen to about 34 million acres, an increase of 62 percent.[2] During the same period total agricultural output, measured in constant dollars, grew at less than half this rate.

---

[1] Michael Straus, "Use of Water for Irrigation," in "The Physical Basis of Water Supply and its Principal Uses," Interior and Insular Affairs Committee, House of Representatives, 1952, p. 62.

[2] Committee Print No. 14, "Reclamation in the West," prepared by the Bureau of Reclamation, Senate Select Committee on National Water Resources. Further references to materials issued by the select committee will be identified simply as "committee print" followed by the appropriate number. Thirty-odd prints issued by the select committee, plus its record of hearings, constitute what is probably the most comprehensive study of water use and occurrence that has ever been prepared for the United States.

Manufacturing industries that use large quantities of water have been growing at rates substantially in excess of the growth of all manufacturing. Only foods and iron and steel fell below the national average rate of growth. Between 1947 and 1954 the major water-using manufactures grew as follows:[3]

[Index of production: 1947=100]

	1954
Pulp and paper	133
Chemicals	153
Petroleum refining	140
Primary aluminum	247
All manufacturing	127
Food	105
Pig iron and steel	107

On a total intake basis, steam-electric utilities (which are not classified among manufactures) account for a larger quantity of water use than any other category except agriculture. Generation of electricity has been growing at roughly 10 percent per year—total generation more than doubling between 1940 and 1950 and again between 1950 and 1960.

Household use has been increasing at a rate substantially in excess of population growth. Per capita urban use exceeds per capita rural use; a larger and larger fraction of our population is becoming urban; and urban per capita use has been been rising steadily.

This study is the latest of several that have appeared within the last decade in response to a succession of attempts to develop a systematic approach to water resource development.[4] But the analytical problems are complex and much still remains to be done. A number of problems beset the study of water use that are applicable to no other resource. Water is fleeting in form, space and time, so that an inventory of its quantity can never be a simple counting up of units of stock. It is subject to wide qualitative variation. Because its availability is taken for granted in most places, we have paid scant attention to measuring its use. Even when it is in short supply we are likely to encounter "wasteful" or "inefficient" uses of water, simply because attention is usually directed toward the economizing of other factors of production.

This preliminary report represents the fruits of a systematic (though still far from completed) attempt to construct national aggregates as the sum of findings for 22 water resource regions. It is the first time in which the natural variation in water supply has been systematically related to estimates of population growth, level of economic activity, use of water and the maintenance of water quality for reasonably homogeneous regions.

A division of the Nation's economy into 22 regions for the study of water use (see frontispiece) poses a dilemma; on the one hand the regions are too small: the range of error attached to projections of population and economic activity grows geometrically as the divison of the national economy into subordinate parts increases. On the other hand the regions are too large: the accuracy with which the quantity and quality of water can be described diminishes at perhaps an equal rate as the geographic area grows. The use of 22 regions is a choice that will satisfy neither economist nor hydrologist; yet it, or something like it, is a necessity to which research techniques must be accommodated.

The analytical model

The procedure followed in preparing this report can best be described as the construction of a "model" and analysis of its properties.

The first step was to postulate the circumstances that would determine water use in 1980 and 2000. Demand for water is a function of direct consumer demand (for drinking, washing, bathing, and recreation) and demand for products that require water (foods and fibers, electric power, paper, gasoline, etc.). We began, therefore, by estimating total and urban population in each water resource region for 1980 and 2000, the quantity of water used per capita and per unit of product, total national output of water-related goods and services, and the regional distribution of production.[5]

---

[3] Indexes are taken from "Resources in the American Future," Resources for the Future, Inc., in preparation.

[4] The President's Water Resources Policy Commission, report, 1950, vols. I, II, and III.

The President's Materials Policy Commission, "Resources for Freedom," June 1952, especially Rept. No. 9, vol. V, by Jack R. Barnes.

Interior and Insular Affairs Committee, "The Physical and Economic Foundation of Natural Resources," House of Representatives, 1952, especially vol. II, "The Physical Basis of Water Supply and its Principal Uses."

Commission on Organization of the Executive Branch, "Task Force Report on Water Resources and Power," vols. I, II, and III, 1955.

D. R. Woodward, "Availability of Water in the United States with Special Reference to Industrial Needs by 1980," thesis prepared for the Industrial College of the Armed Forces, 1957.

Kenneth A. MacKichan, "Estimated Use of Water in the United States, 1955," Geological Survey Circular 398, 1957.

[5] The supply of water was specifically ignored as a limiting factor, except in obvious cases already affected by water shortage. The terms "supply" and "demand" are not used in the economist's sense of a schedule relating price and quantity, but in the sense of physical requirements based on postulated economic activity (demand) and physical availability based on the flow-frequency curve and quantity of storage (supply).

From these estimates we constructed regional totals of water for "withdrawal uses," "onsite uses," and "flow uses."

"Withdrawal uses" are those that require withdrawal of water from a place of natural occurence into a well-defined hydraulic system: irrigation (plus stock watering and rural domestic use), mining, manufacturing, steam-electric power and the domestic, commercial, and small manufacturing needs met by municipal systems. "Onsite uses" are defined as the water requirements for land treatment and structure programs designed to conserve soil and moisture, and the water requirements of swamps and wetlands that serve as wildlife habitat. "Flow uses" are navigation, hydroelectric power, sport fish habitat, waste dilution, and fresh-water discharge into estuarine waters utilized for commercial fisheries.

We constructed two measures of water use: a "gross" figure showing total withdrawals or total onsite applications and a "net" figure that showed the amount of water lost to the atmosphere or incorporated into the product from these uses.

Because water can be reused, an excess of gross use over supply is not an automatic indicator of water shortage. Accordingly, we postulated the following questions: if water is utilized in accordance with indicated projections of demand and indicated quantity of reuse, what is the average quality of water that must be maintained if these uses are all to be met? By what method or methods is quality maintained for the region as a whole?

If all waste, or at any rate all water-deteriorating elements, could be removed by treatment, a region's water supply could be used over and over. The limits of water use would be reached only when the last drop of water escaped from the region by evaporation, was discharged into the sea, or otherwise became physically unavailable. But there are many reasons why this ideal cannot be approached in actual practice.

In addition to the need for water that is consumed in the process of use, water is needed for mixing with the discharge of effluent from waste treatment plants. Water that carries human and other organic wastes undergoes chemical change even if complete sewage treatment is rendered. Under present technology of waste treatment, unless the treated sewage effluent can be mixed with water of higher quality, stream quality will deteriorate to the point where it will be incapable of maintaining desirable aquatic life, will be inferior for domestic supply and may detrimentally influence environmental conditions.

Waste treatment cannot be carried up to 100 percent removal with a corresponding reduction to zero of dilution water because of a secondary oxygen demand induced by the treatment itself. As a consequence of high level treatment the resulting effluent carries nitrogen and phosphorous which stimulate the growth of algae. The increase in algae and their subsequent death and decay create offensive conditions, objectionable tastes and odors, and a demand for oxygen that, under presently known technology, can be offset only by an adequate flow of water in the stream.

A systematic relationship can be established among the uses to which water is put, the resulting amount of waste, level of waste treatment, and the quantity of streamflow needed to maintain a designated oxygen content of the stream.[6] Other pollutants also must be considered, but it was established that if adequate dilution were provided for oxygen depleting waste substances [7] and algae, the adverse effects of other unavoidable pollutants, except for special circumstances, would generally be offset.

With these relationships in hand, therefore, it was possible to formulate the following proposition: A region can meet all requirements for water provided its supply is equal to or more than the sum of losses incurred from use plus the amount of flowing water needed for waste dilution in order to assure a specified content of dissolved oxygen in its streams. Although formidable difficulties of measuring these quantities still remained, our model yielded a determinate answer to the question: What are total water requirements within a region for direct consumer uses and for the output of goods and services? For each region the sum of losses plus total streamflow that would assure adequate waste dilution was specified as the "required flow." [8]

---

[6] See below, pt. II. These relationships were developed for each water resource region by George Reid, director of the Water Resources Research Bureau of the University of Oklahoma in his capacity as consultant to the U.S. Public Health Service. See Committee Print No. 29.

[7] Depletion of oxygen in stream water by waste is known as "biochemical oxygen demand," or, more briefly, BOD.

[8] As explained in pt. II, it is assumed that if the "required flow" is provided, withdrawal requirements at a particular point can also be met.

The "required flow" is not only a function of water use; it also depends upon the amount of oxygen-depleting organic material that is removed from the waste. If 80 percent of the biochemical oxygen demand (BOD) is removed, the dilution needed is one-half the amount required if 60 percent of BOD is removed. (The residual BOD load dumped into the streams in the former case is half the residual of the latter.) Hence, for each level of BOD removal, on a scale which was considered as ranging from 50 to 97½ percent treatment for manufacturing wastes and from 70 to 97½ percent for municipal wastes, the required dilution in order to maintain stream oxygen at 4 milligrams of oxygen per liter of water, can be specified.[9] The provision of an adequate supply of satisfactory water—reasonably clean, reasonably free of odor, and able to maintain a reasonably satisfactory variety of stream life—involves a combination of treatment of waste and regulation of flow. The magnitude of the one is dependent upon the magnitude of the other. The "demand for water," in its most general meaning, is a demand for sustained flow after accounting for losses, to take care of the biochemical oxygen demand still remaining in the effluent discharged from treatment plants.

In the course of our study both supply and demand were measured as average daily quantities: Total annual withdrawals were converted to millions of gallons per day (MGD); flow uses that were originally expressed as instantaneous rates of flow (cubic feet per second) were also converted to millions of gallons per day. Supply was measured as the amount of surface runoff within a region, in millions of gallons per day, equaled or exceeded 95, 90, 80, 70, and 50 percent of the time, and the longrun average. The flow equaled or exceeded 95 percent of the time was considered to be the present low flow. The longrun average was considered to be the theoretical maximum sustained flow after an adjustment was made for reservoir losses. Additional storage needed to raise the present minimum flow to successively higher flows, up to the average, available 100 percent of the time was ascertained. It then became possible to compare the projected required flow in a region for 1980 and 2000 with existing minimum flows and to determine the amount of storage capacity, if any, that would have to be installed. The "required flow" was the minimum flow that could be tolerated under the most adverse circumstances, namely, during the period of high temperatures and *normally experienced low flows*. A problem might have been encountered if the "required flow" had been specified as a daily average, capable of fluctuation from season to season, or as a minimum flow for a part of the year other than that in which the low flows normally occurred. Had such been the case, the quantity of required storage would not have been determinate unless additional, and in most instances local, facts had been ascertained.[10]

At the outset it was decided that concepts of supply and demand would be limited to the use of water derived from runoff. Precipitation, except as it contributes to runoff, and water loss prior to runoff, were outside the scope of our measurements. Prospective changes in ground cover or land use that will result in decreases in runoff are included, however, as increases in demand rather than as decreases in supply. This distinction was applicable to water requirements for soil and moisture conservation practices (land treatment and structures) and to requirements for swamps and wetlands needed for ducks, geese, and other wildlife.

Ground water was not treated as a separate element of supply. Insofar as underground storage contributes to surface runoff, it is implicitly included in our measure of supply. Insofar as use of ground water reduces surface runoff, there is no need to distinguish between the two sources of supply. A short-term error is involved in reconciling supply with use to the extent that ground water is mined. Another error stemming from ground water usage is the possibility of substituting underground storage for surface storage and, therefore, overstating the quantity of surface storage that might be needed. Our knowledge of the incidence and movement of ground water is not yet detailed enough to permit a more satisfactory integration of ground and surface supplies to be made.

---

[9] About 4 parts of oxygen per million parts of water. This is an average for the region. In parts of the region the dissolved oxygen content would presumably be higher at the expense of a lower content elsewhere.

[10] Irrigation requirements are seasonal, but not necessarily coincidental with the natural variability of streamflow. It was established that, in general, storage requirements for irrigation were about the same whether irrigation requirements were computed on the basis of seasonal concentration or as an average daily requirement without regard to seasonal variation.

Our model contained the elements out of which a supply curve of reservoir capacity was constructed for each region. This supply curve related increments of storage capacity to increments of costs. We were also able to construct a supply curve of treatment, relating increments of treatment with increments of treatment costs. As indicated above, for each region we had a schedule that related increments of storage to increments of sustained flow, and a schedule that related level of waste treatment with level of required dilution flow. By studying the interaction among all variables we could ascertain the following for each water resource region for 1980 and 2000:

(*a*) Losses from projected uses;

(*b*) Waste dilution flows at different levels of BOD removal, costs of treatment at each level;

(*c*) Sum of losses and waste dilution flows combined into a single "required flow" for different levels of treatment;

(*d*) Present minimum flows, maximum possible sustained flows, frequency of intermediate flows, storage requirements for increases in sustained flow and estimated costs of storage by increments of storage,

(*e*) The degree to which a region could or could not meet projected requirements even if full regulation were adopted;

(*f*) The combinations of treatment and flow regulation available to a region;

(*g*) The costs for each region and for the Nation as a whole of alternative storage-treatment programs.

Several characteristics of our model should be noted at this point. First, by relating surface flow to level of waste treatment, both of these become intrinsic elements of a "water resource program." Since under present technology additional regulation of flow for all purposes is achieved mainly by surface storage, the basic national water resources program becomes, in effect, a program of reservoirs and waste-treatment plants.

Second, not all needed storage capacity is necessarily indicated by our model. Deviations from indicated results may originate in several ways: flood control reservoirs in excess of the storage capacity required to regulate flow; reservoir space to provide head for hydroelectric power; dead storage used for recreation and silt deposition; dams and locks required for navigation. These requirements, over and above those for flow regulation, could not be stipulated except after detailed project studies and, therefore, could not be incorporated into our general water resource program.

Several additional qualifications of our model can be noted. In particular subbasins a seasonal concentration of need when combined with natural variability of flow may require more or less storage than is indicated when requirements are converted to an average daily figure. Measures of water use in many instances are estimates based upon limited observations. The distribution of available storage sites was deduced from the existing distribution; further investigation might indicate a need for modifying estimated costs of reservoir construction either upward or downward.

Perhaps more important than any of the foregoing are the possible changes in water use induced by new technology and by possible innovations in economic and administrative policies that influence water use. For example, methods of impounding waste for release during periods of high flow might reduce aggregate storage requirements. (Waste rather than clean water would be stored.) Oxygen might be artificially added at some stage of waste treatment; a method of inducing rapid growth of algae and harvesting it for use might be developed. These as well as other techniques could lower the need for waste dilution. In regions marked by serious water shortage a more extensive reliance upon pricing techniques for the allocation of water among uses might result in a revision of the projected patterns of use. Until further research has been done on these and related questions, it is not possible to do more than speculate on the results.

All projections—population, economic activity, and water use—were made for three levels: high, medium, and low. *This report is limited to a dis-*

cussion of the medium series. The following tabulation shows the spread of the three series for 1980 and 2000 for the United States as a whole, compared with 1954:

	1954	1980			2000		
		Low	Medium	High	Low	Medium	High
Population (million) [1]	162	225	244	278	267	329	431
GNP (billions of 1960 dollars) [1]	426	960	1,060	1,200	1,680	2,200	3,200
Water (billion gallons per day):							
Total withdrawals	300	456	559	849	545	888	1,608
Losses charged against available runoff	109	170	190	246	170	253	373

[1] From "Resources in the American Future," op. cit.

The range between high and low for total withdrawals of water in 1980 is 200 percent and for 2000 is 300 percent. This uncertainty is a reflection of uncertainty in the overall growth of the economy as well as in the possible magnitude of intercommodity substitution. While a "prediction" that is hedged with a 300-percent range of possible amplitude may be of little practical value to someone compelled to make a decision today, it would be naive to assume that even this range exhausts all possible developments. At best, we can chart a course for the future, and as each year's experience is recorded we can quicken or retard, as need be, the pace of development that is adopted.

The findings

I. The major depleting uses are irrigation and the provision of swamp and wetland habitat for, mainly, waterfowl. The major sources of pollution are household uses and the manufacture of foods, pulp and paper, chemicals, and petroleum products. Required flows are roughly proportional to the magnitudes of depleting and polluting uses.

II. The following tabulation shows the major changes in water use, except for waste dilution flows, estimated for 1980 and 2000 for the Nation as a whole:

	Billions of gallons per day		
	1954	1980	2000
Withdrawal uses—withdrawals:			
Agriculture	176	167	184
Mining	1	3	4
Manufacturing	32	102	229
Thermal power	74	259	429
Municipal	17	29	42
Total	300	559	888
Losses charged against available runoff:			
Withdrawal uses	109	119	[illegible]
Onsite uses [1]	...	71	97
Total	109	190	253

[1] 1954 onsite uses assumed to be reflected in runoff. Only increases above 1954 are assumed to result in reduced runoff.

III. Waste dilution flows for 1980 and 2000 were computed for various levels of treatment designed to provide a dissolved oxygen content of 4 milligrams per liter in the stream. In 1980 the range for municipal treatment extended from 70-percent BOD removal to 97½ percent; in 2000 the range extended from 80 to 97½ percent. The range for industrial treatment extended from 50 to 97½ percent for both years. When losses are added to streamflows needed for satisfactory waste dilution, the required flow for each region under projected conditions of population, economic activity, degree of waste treatment, and quality of streamflow (i.e., 4 milligrams per liter of dissolved oxygen) is given. Costs for each level of waste treatment can be estimated. In the following table the required flows and costs of waste treatment are given for each level of waste treatment for the country as a whole. (Where two numbers are shown under

"Percent treatment" the first refers to municipal sewage and the second to industrial wastes):

1980			2000		
Percent treatment	Annual cost	Total flows (BGD)	Percent treatment	Annual cost	Total flows (BGD)
	Billions			*Billions*	
70/50	$0.9	1,298	80/50	$1.8	1,919
70/60	1.0	1,145	80/60	1.9	1,653
70	1.2	999	80/70	2.4	1,382
80	1.7	670	80	2.9	1,130
90	2.3	480	90	3.9	732
95	2.6	399	95	4.5	612
97½	2.8	400	97½	4.9	613

NOTE.—"Annual costs" include collection and treatment and cover operation, maintenance, and amortization.

IV. The foregoing schedule of required flows and costs of treatment can be compared with the amounts of storage and costs of storage needed to yield a given sustained flow. By adding storage appropriately throughout the country in accordance with the following schedule, minimum flows would respond in the manner shown in the column headed "sustained flow." The schedule is constructed on the assumption that increments of storage are added in order progressing from large size, low cost reservoir sites to small size, high cost sites. The distribution of total added capacity among reservoirs of various sizes was derived from the 1954 distribution.

Average size reservoir	Cumulative added storage capacity	Sustained flow	Annual costs
Thousand acre-feet	*Thousand acre-feet*	*Million gallons per day*	*Millions*
7,000	70,540	118,500	$164
3,000	153,190	200,270	325
1,500	300,722	409,900	661
700	469,150	620,530	1,027
300	586,047	729,300	1,309
150	696,074	813,320	1,750
80	766,621	859,450	2,146
50	805,396	880,770	2,227
30	837,555	895,810	2,389
10	844,054	905,740	2,583

V. Given the cost of treatment and required flow for each level of treatment, and the amount and cost of storage for each required flow, it is possible to ascertain total treatment and storage costs of any combination of treatment and flow that falls *within the capability limits of the region*. When this is done for all regions and aggregated into national totals, we can compare the major elements of several alternative programs. Three programs were postulated: (1) maximum treatment and minimum storage; (2) minimum treatment and maximum storage; (3) minimum aggregate costs of treatment and storage. In formulating the programs it was assumed that where there was a water shortage in spite of maximum treatment and maximum storage, the region would carry both treatment and storage to maximum levels regardless of the program. Tables 1 to 6, inclusive, summarize the three programs for 1980 and 2000. Tables 1 and 2 contain some additional information as well. Table 1 shows the quantity of reservoir capacity in each region as of 1954, the average undepleted flow prior to depletions from use and the average supply still available after current depletions. Table 1 shows losses from withdrawal and on site uses projected to 1980; table 2 gives this information for 2000. All six tables show the waste dilution flows, percent treatment, total required flow and storage requirements to yield the required flow. In regions in which required flows exceed runoff, the storage that will yield maximum sustained flow is given. Regardless of program, it was assumed that in water-short regions, treatment is carried to the point at which dilution flows are minimized. All tables show the cost of waste treatment, municipal and industrial, at indicated levels of treatment, and the costs of storage to yield required or maximum attainable flow where the latter was less than the former, as the case may be. All costs are annual costs including amortization. Tables 5 and 6, showing "minimum treatment" programs are minimums only within two limitations: (1) the lowest assumed level of treatment in any region was 50 percent for industrial waste and 70 percent for municipal waste in 1980 and 80 percent in 2000 regardless of available flow; (2) in regions in which available runoff was less than that required for 70 percent municipal/50 percent industrial treatment in 1980 or 80 percent municipal/50 percent industrial in 2000, the level of treatment was the lowest consistent with maximum sustained flow. In a number of regions the level of treatment consistent with maximum sustained flow was shown as falling between designated limits, e.g. as between 80 and 90 percent.

TABLE 1.—*Summary: Minimum storage program, 1980*

	Present storage and supply of water			1980 requirements					Annual costs (million dollars)		
	Storage, 1954 (thousand acre-feet)	Average undepleted flow (million gallons per day)	Average flow still available (million gallons per day)	Losses (million gallons per day)	Waste dilution (million gallons per day)	Percent treatment	Required flow (million gallons per day)	Required additional storage (thousand acre-feet)	Storage	Collection and treatment	Total
New England	9,000	67,000	67,000	1,500	8,980	97.5/97.5	10,500	2,400	7	162	169
Delaware and Hudson	3,100	32,000	32,000	2,100	11,440	95/95	13,500	5,800	18	189	207
Chesapeake Bay	900	52,000	52,000	1,500	13,2[illegible]	95/95	14,700	4,300	15	213	228
Southeast	16,400	212,000	212,000	19,400	17,000	90/90	36,400	9,800	15	166	181
Eastern Great Lakes	500	40,000	40,000	1,800	13,980	95/95	15,800	8,500	17	156	173
Western Great Lakes	1,200	42,000	42,000	4,300	31,900	95/95	36,200	34,000	57	254	311
Ohio	5,700	110,000	110,000	2,200	14,800	70/70	17,000	8,510	13	117	130
Cumberland	6,400	17,000	17,000	200	1,885	95/95	2,100	295	0	24	24
Tennessee	15,000	43,000	43,000	500	3,840	95/95	4,300	124	0	52	52
Upper Mississippi	4,300	62,000	62,000	5,100	13,900	95/95	19,100	5,800	8	197	205
Lower Mississippi	4,500	49,000	49,000	9,500	4,210	90/90	13,700	8,500	6	65	71
Upper Missouri	74,800	29,000	19,000	29,200	4,352	95/95	33,600	[1] 30,000	43	95	138
Lower Missouri	1,200	23,000	23,000	400	1,800	80/80	2,200	2,350	2	21	23
Upper Arkansas-White-Red	7,300	13,000	11,000	5,300	2,610	97.5/97.5	7,900	8,000	8	49	57
Lower Arkansas-White-Red	28,800	77,000	77,000	4,000	3,865	90/90	7,900	9,600	6	43	49
Western Gulf	11,200	46,000	46,000	20,500	8,670	95/95	29,200	25,500	30	172	202
Upper Rio Grande and Pecos	3,300	3,550	0	6,300	1,000	97.5/97.5	7,300	[1] 7,400	13	14	27
Colorado	35,100	13,500	3,200	17,100	2,229	95/95	19,300	[1] 14,500	20	29	49
Great Basin	4,100	10,500	3,700	10,900	1,200	97.5/97.5	12,100	[1] 6,500	14	31	45
Pacific Northwest	28,900	143,000	143,000	13,900	14,800	90/90	28,700	10,800	37	155	192
Central Pacific	16,400	58,000	47,000	30,700	5,200	90/90	35,900	25,500	43	96	139
South Pacific	1,800	1,000	360	4,000	6,330	97.5/97.5	10,300	[1] 650	2	107	109
United States	278,000	1,145,000	1,100,000	190,400	187,281		377,700	228,829	374	2,407	2,781

[1] Maximum.

Sources: See references in pts. II and III.

TABLE 2.—*Summary: Minimum storage program, 2000*

	Losses (million gallons per day)	Waste dilution (million gallons per day)	Percent treatment	Required flow (million gallons per day)	Required additional storage (thousand) acre-feet	Annual costs (million dollars)		
						Storage	Collection and treatment	Total
New England	2,[illegible]33	16,920	97.5	19,453	6,100	18	305	323
Delaware and Hudson	3,077	16,720	90	19,767	12,000	43	237	280
Chesapeake Bay	3,138	23,820	95	26,958	14,500	54	337	391
Southeast	32,565	32,350	90	64,915	21,500	32	277	309
Eastern Great Lakes	2,950	23,700	97.5	26,650	20,000	43	331	374
Western Great Lakes	7,854	51,200	95	59,054	[1] 50,000	94	431	525
Ohio	4,913	23,200	80/70	28,113	16,000	29	244	273
Cumberland	371	3,400	90	3,771	810	1	33	34
Tennessee	1,116	7,470	95	8,586	380	0	108	108
Upper Mississippi	10,959	21,750	95	32,709	17,000	32	307	339
Lower Mississippi	13,454	11,320	90	24,774	18,000	14	49	63
Upper Missouri	40,066	10,990	95	51,056	[1] 30,000	43	144	187
Lower Missouri	1,815	3,210	80	5,025	4,900	5	36	41
Upper Arkansas-White-Red	7,129	4,600	97.5	11,700	[1] 13,000	22	78	100
Lower Arkansas-White-Red	6,361	6,060	95	12,421	14,600	10	81	91
Western Gulf	28,691	14,800	95	43,491	[1] 34,000	51	346	397
Upper Rio Grande and Pecos	6,692	3,610	95	10,302	[1] 7,400	13	29	42
Colorado	17,159	4,513	95	21,672	[1] 14,500	20	66	86
Great Basin	11,812	1,700	97.5	13,512	[1] 6,500	14	48	62
Pacific Northwest	16,340	19,590	90/90	35,800	14,700	48	241	289
Central Pacific	29,853	9,900	90	39,753	27,800	48	190	238
South Pacific	4,303	11,400	97.5	15,703	[1] 650	2	208	210
United States	253,151	322,133		575,185	344,340	636	4,126	4,762

[1] Maximum.

Sources: See references in pts. II and III.

TABLE 3.—*Summary: Minimum cost program, 1980*

	Waste dilution (million gallons per day)	Percent treatment	Required flow (million gallons per day)	Required additional storage (thousand acre-feet)	Annual costs (million dollars)		
					Storage	Collection and treat-	Total
New England	12,700	95 /95	14,200	3,400	10	152	162
Delaware and Hudson	11,700	90 /90	13,800	6,100	20	167	187
Chesapeake Bay	22,500	90 /90	24,000	11,200	36	182	218
Southeast	55,950	70 /90	75,400	28,000	40	79	119
Eastern Great Lakes	13,980	95 /95	15,800	8,500	17	156	173
Western Great Lakes	31,900	95 /95	36,200	34,000	57	254	311
Ohio	17,215	70 /50	19,400	10,100	16	100	116
Cumberland	7,500	70 /60	7,700	3,300	3	8	11
Tennessee	23,850	70 /60	24,400	6,400	6	17	23
Upper Mississippi	25,272	90 /90	30,400	14,000	26	172	198
Lower Mississippi	12,720	70 /50	22,200	15,800	12	23	35
Upper Missouri	4,352	95 /95	33,600	[1] 30,000	43	95	138
Lower Missouri	3,150	70 /60	3,600	3,600	3	12	15
Upper Arkansas-White-Red	2,610	97.5/97.5	7,900	8,000	8	49	57
Lower Arkansas-White-Red	12,980	70 /60	16,900	20,000	16	18	34
Western Gulf	20,400	80 /80	40,900	[1] 34,000	51	109	160
Upper Rio Grande and Pecos	1,000	97.5/97.5	7,300	[1] 7,400	13	14	27
Colorado	2,220	95 /95	19,300	[1] 14,500	29	29	49
Great Basin	1,200	97.5/97.5	12,100	[1] 6,500	14	31	45
Pacific Northwest	28,900	70 /90	42,800	19,200	66	54	120
Central Pacific	13,800	70 /90	44,500	31,000	58	46	104
South Pacific	6,330	97.5/97.5	10,300	[1] 650	2	107	109
United States	332,158	....	522,700	315,650	537	1,874	2,411

[1] Maximum.

TABLE 4.—*Summary: Minimum cost program, 2000*

	Waste dilution (million gallons per day)	Percent treatment	Required flow (million gallons per day)	Required additional storage (thousand acre-feet)	Annual costs (million dollars)		
					Storage	Collection and treatment	Total
New England	16,920	97.5	19,453	6,100	18	305	323
Delaware and Hudson	16,720	90	19,767	12,000	43	237	280
Chesapeake Bay	23,820	95	26,958	14,500	54	337	391
Southeast	66,825	80/70	99,390	49,000	73	190	263
Eastern Great Lakes	26,000	95	28,950	22,800	51	299	350
Western Great Lakes	51,200	95	59,054	[1] 50,000	94	431	525
Ohio	29,370	80/50	31,283	20,300	39	201	240
Cumberland	12,300	80/60	12,671	7,800	8	13	21
Tennessee	28,575	80	29,691	12,000	12	68	80
Upper Mississippi	21,750	95	32,709	17,000	32	307	339
Lower Mississippi	22,620	80/70	36,074	29,000	25	28	53
Upper Missouri	10,990	95	51,056	[1] 30,000	43	144	187
Lower Missouri	5,280	80/60	7,095	6,700	8	22	30
Upper Arkansas-White-Red	4,600	97.5	11,700	[1] 13,000	22	78	100
Lower Arkansas-White-Red	20,900	80/60	27,261	[1] 32,000	30	33	63
Western Gulf	14,800	95	43,491	[1] 34,000	51	346	397
Upper Rio Grande and Pecos	3,610	95	10,302	[1] 7,400	13	29	42
Colorado	4,513	95	21,672	[1] 14,500	20	66	86
Great Basin	1,700	97.5	13,512	[1] 6,500	14	48	62
Pacific Northwest	28,000	80/70	44,340	20,400	70	131	201
Central Pacific	24,600	80/60	54,453	36,500	77	105	182
South Pacific	11,400	97.5	15,703	[1] 650	2	208	210
United States	446,493	....	699,585	442,150	799	3,626	4,425

[1] Maximum.

TABLE 5.—*Summary: Minimum treatment program, 1980*

	Required flow (million gallons per day)	Percent treatment	Required additional storage (thousand acre-feet)	Annual costs (million dollars)		
				Storage	Collection and treatment	Total
New England*	65,000	70–80	90,000	473	78	551
Delaware and Hudson*	31,000	70–80	29,000	145	111	256
Chesapeake Bay*	50,800	70–80	52,000	261	118	379
Southeast	82,000	70/50	31,000	45	77	122
Eastern Great Lakes*	38,600	80–90	37,000	99	124	223
Western Great Lakes*	40,000	90–95	50,000	123	249	372
Ohio	19,000	70/50	10,100	16	100	116
Cumberland	9,000	70/50	4,600	5	7	12
Tennessee	30,400	70/50	13,600	15	16	31
Upper Mississippi*	58,900	70–80	62,500	185	118	303
Lower Mississippi	22,200	70/50	15,800	12	23	35
Upper Missouri*	33,600	95	30,000	43	102	145
Lower Missouri	4,000	70/50	4,000	10	21	31
Upper Arkansas-White-Red*	10,500	90–95	13,000	23	44	67
Lower Arkansas-White-Red	18,800	70/50	22,000	18	17	35
Western Gulf*	40,900	80	34,000	51	109	160
Upper Rio Grande and Pecos*	7,300	97.5	7,400	13	14	27
Colorado*	19,300	95	14,500	20	29	49
Great Basin*	12,100	97.5	6,500	14	31	45
Pacific Northwest	47,600	70/50	22,800	79	49	128
Central Pacific	46,400	70/50	32,000	61	44	105
South Pacific	10,300	95	650	2	107	109
United States	697,700		582,450	1,713	1,588	3,301

* The minimum treatment program within limits of each region's water supply. For water-short regions, the flow given is that required by the minimum flow program, although it exceeds regional supply. Maximum storage is required in all regions marked by an asterisk.

TABLE 6.—*Summary: Minimum treatment program, 2000*

	Required flow (million gallons per day)	Percent treatment	Required additional storage (thousand acre-feet)	Annual costs (million dollars)		
				Storage	Collection and treatment	Total
New England*	65,000	80–90	90,000	473	228	701
Delaware and Hudson*	31,000	80–90	29,000	145	189	334
Chesapeake Bay*	50,800	80–90	52,000	261	263	524
Southeast	121,000	80/50	75,000	139	167	306
Eastern Great Lakes*	38,600	90–95	37,000	99	282	381
Western Great Lakes*	40,000	95	50,000	94	431	525
Ohio	34,300	80/50	20,300	39	201	240
Cumberland*	15,400	80/50	11,000	13	12	25
Tennessee*	42,600	80/70	44,000	82	50	132
Upper Mississippi*	58,900	80–90	62,500	185	246	431
Lower Mississippi*	49,100	80/50	41,000	42	21	63
Upper Missouri*	51,100	95	30,000	43	144	187
Lower Missouri	8,200	80/50	7,600	10	21	31
Upper Arkansas-White-Red*	11,700	97.5	13,000	22	78	100
Lower Arkansas-White-Red	31,600	80/50	38,000	40	29	69
Western Gulf*	43,500	95	34,000	51	346	397
Upper Rio Grande and Pecos*	10,300	95	7,400	13	29	42
Colorado*	21,700	95	14,500	20	66	86
Great Basin*	13,500	97.5	6,500	14	48	62
Pacific Northwest	67,200	80/50	40,500	140	88	228
Central Pacific*	55,300	80/50–60	38,000	83	102	185
South Pacific*	15,700	97.5	650	2	208	210
United States	876,500		741,950	2,010	3,249	5,259

*The minimum treatment program within limits of each region's water supply. For water-short regions, the flow given is that required by the minimum flow program, although it exceeds regional supply. Maximum storage is required in all regions marked by an asterisk.

VI. Storage requirements: Regardless of the program that is adopted, five regions would require maximum regulation by 1980, and these five plus three more by 2000. The five are upper Missouri, upper Rio Grande and Pecos, Colorado, Great Basin, and South Pacific. The three additional are Western Great Lakes, upper AWR, and Western Gulf. Seventeen regions in 1980 and 14 regions in 2000 have a choice of storage and treatment combinations. Aggregate storage capacity varies in the following way by choice of program (million acre-feet):

	1980	2000
Maximum treatment, minimum storage	229	344
Minimum total cost	316	442
Maximum storage, minimum treatment	582	742

VII. Waste treatment requirements: By 1980 only nine regions would have enough water supply to tolerate the minimum stipulated levels of waste treatment, i.e., 70 percent for municipal and 50 percent for industrial wastes, with maximum sustained flows. In the remaining 13 regions, minimum levels of treatment would range between 70 and 97½ percent. By 2000, seven regions could be at the 50-percent level of industrial waste treatment, and one between 50 and 60 percent. Thirteen regions would require treatment of 80 percent or higher for both municipal and industrial wastes. The minimum cost programs would require treatment in excess of 50 percent for industrial wastes for all except two regions in 1980 and for all except one in 2000.

VIII. Annual costs of storage and waste treatment programs: Corresponding to the variation in storage capacity by program are the costs of storage, collection and treatment, and total costs. Annual costs including amortization for the Nation as a whole would vary as follows:

[In millions of dollars]

	1980	2000
Annual costs of storage:		
Program:		
Maximum treatment, minimum storage	374	636
Minimum total cost	537	799
Maximum storage, minimum treatment	1,713	2,010
Annual costs of collection and treatment:		
Program:		
Maximum treatment, minimum storage	2,407	4,126
Minimum total cost	1,874	3,626
Maximum storage, minimum treatment	1,591	3,249
Annual total costs:		
Program:		
Maximum treatment, minimum storage	2,781	4,762
Minimum total cost	2,411	4,425
Maximum storage, minimum treatment	3,301	5,259

IX. Capital costs of programs: The relationship between annual costs and capital outlays is approximately the same, on the average, for waste treatment and storage regulation, although of course many individual variations will be encountered. On the assumption that annual costs of operation, maintenance and amortization are equal to 4.5 percent of capital costs [11] (based on an interest rate of 2½ percent), the following figures show the estimated additions to capital facilities for 1980 and 2000. For both years the figures are cumulative increases in investment over present (1954) levels:

[In billions of dollars]

	1954-80	1954-2000
Capital costs of storage:		
Program:		
Maximum treatment, minimum storage	8.4	14.3
Minimum total cost	12.1	18.0
Maximum storage, minimum treatment	38.5	45.2
Capital costs of collection and treatment:		
Program:		
Maximum treatment, minimum storage	54.2	92.8
Minimum total cost	42.2	81.6
Maximum storage, minimum treatment	35.8	73.1
Total capital costs, storage, collection and treatment:		
Program:		
Maximum treatment, minimum storage	62.6	107.1
Minimum total cost	54.2	99.6
Maximum storage, minimum treatment	74.3	118.3

X. A "maximum treatment, maximum storage" program: If we were to combine the level of treatment required by the maximum treatment program with the level of storage required by the minimum treatment program for 1980, the totals would provide about one-third more treatment (measured in cost) and about one-third more flow (measured in millions of gallons per day of sustained flow) than the minimum cost program for the same year. It represents a demand for treatment and storage that would correspond, roughly, to a growth of the economy to a point one-third greater than the medium projections on which all of the foregoing has been based. Since the high water use projected for 1980 was approximately 1½ times the medium projection, measured by total withdrawals, a demand that is one-third greater than the medium projection falls well within the limits of probability.

[In millions of dollars]

	1980	2000
Annual costs would be—		
Maximum treatment	2,407	4,126
Maximum storage	1,713	2,010
Total	4,120	6,136
Capital costs would be—		
Maximum treatment	54,200	92,800
Maximum storage	38,500	45,200
Total	92,700	138,000

XI. Adjustment to water shortages—five western regions: In five regions projected losses alone (without taking waste dilution into account) in

---

[11] If capital costs of collection and treatment are derived from annual costs by assuming a scale of capitalization rates ranging between 3⅓% for 60% treatment and 6% for 97½% treatment (see Reid, *op. cit.*, p. 10), the net effect is a reduction in capital values, since treatment in excess of 80%, for which the rate of capitalization is 4½%, dominates all programs. Differences in capitalized values derived from the two methods range between one and eight billion dollars, depending upon program, for 1980; and between five and fifteen billion dollars, depending upon program, for 2000. The greatest differences appear, of course, for the minimum storage program.

1980 and 2000 exceed the maximum sustained flow capable of being developed. These are the Upper Missouri, Rio Grande, Colorado, Great Basin, and South Pacific. A summary of estimated losses based upon the medium projected rates of growth and economic activity is given in table 7, with a column showing maximum potential sustained flow after adjusting for reservoir losses. Unless new technologies of water use are discovered, or unless supplies are augmented by importation (already a substantial source of supply for South Pacific), weather modification, modification of runoff, or desalinization, projected patterns of use are impossible of fulfillment. Since water appears to be the ultimate limiting factor to population and general economic growth in these regions, it is likely that water "extensive" activities—agriculture and wildlife propagation—will decline relative to water "intensive" activities—domestic and industrial uses—unless institutional barriers prevent this transfer. However, unless the goods and services foregone in the regions of water shortage are produced elsewhere, national output of these items will fall below projected requirements. By stimulating an interregional rearrangement of production, the effects of water shortage in the West are likely to be felt over much of the economy

TABLE 7.—*5 western regions: Losses and sustained flows, 1980 and 2000, medium projections*

	Maximum sustained flow (million gallons per day) [1]	Losses: 1980				Losses: 2000				Sustained yield as a percent of estimated loss	
		Irrigation	Fish and wildlife	All other	Total	Irrigation	Fish and wildlife	All other	Total	1980	2000
Upper Missouri	27,000	15,000	13,000	1,000	29,000	20,000	18,000	2,000	40,000	93	68
Rio Grande	1,000	5,000	1,100	200	6,300	4,800	1,500	400	6,700	16	15
Colorado	10,000	14,000	2,000	1,100	17,100	13,000	2,600	1,600	17,200	58	58
Great Basin	9,000	6,700	4,000	200	10,900	6,100	5,300	400	11,800	83	76
South Pacific [2]	300	3,300	----------	700	4,000	3,100	----------	1,200	4,300	8	7

[1] After adjusting for reservoir losses.
[2] Requirements now largely met by importation of water.

Conclusions

A number of conclusions emerge from the findings:

1. The main feature of a national water resources program for the next few decades is the provision of a regulated supply of clean water capable of satisfying a variety of uses. If this is accomplished, the main elements of most other water resource problems can be simultaneously met.

2. The seriousness of water shortage in the West is confirmed. If the West is to share in projected population and economic growth one or more of the following adjustments in the projections for 1980 and 2000 must take place:

(*a*) An increase in water supply by importation, desalinization, increase in runoff by modification of land cover or control of snowmelt, or increase in precipitation by modification of weather.

(*b*) An increase in efficiency of water use—in irrigation, wildlife habitat, and other uses—beyond that which is anticipated.

(*c*) A reduction in heavy water depleting uses—irrigation and wildlife habitat—in order to allow fulfillment of other uses. In four of the five western regions marked by water shortage (all except South Pacific), from 85 to 90 percent of estimated minimum flow is required to offset losses resulting from the projected level of irrigation and the projected increase in swamps and wetlands required for wildfowl.

3. The major demand upon our water resources in the East is for an adequate supply for waste dilution. On the assumption that adequate overall quality of water is assured only if streamflow is sufficient to maintain an average dissolved oxygen content of 4 parts per million, such dilution is required over and above a comparatively high level of waste treatment. In the East, approximately 90 percent of estimated flows for 1980 and 2000 are required to dilute the projected levels of waste discharge.

4. The simultaneous need for an adequate program of waste treatment and flow regulation im-

poses joint responsibilities upon the public (local, State, and Federal) and private sectors of the economy to coordinate programs for waste treatment and river regulation.

5. In order to minimize dislocations and awkwardness of adjustment to the growing shortage of water in the West, and to attain a maximum degree of flexibility in meeting the problems of deteriorating water quality in the East, an expanded research program in all phases of water occurrence, behavior, and use is in the public interest. Since various research needs have been discussed in other publications of the select committee, the following list is limited to items germane to the material of this report.

(*a*) An acceleration of research in basic geology and hydrology designed to fill various gaps in our knowledge of the movement, chemical change, and loss of water. For example, we cannot systematically incorporate use of underground storage into a comprehensive analysis of water supply and demand until we have more knowledge about underground water.

(*b*) Potential changes in technology of water use. We do not know what are the possible or probable limits of variation in water loss per unit of product or in waste dilution requirements per unit of water discharge.

(*c*) Current facts of water use. Existing measures derived from one source are not always consistent with measures derived from other sources.

(*d*) Costs of storage, conveyance, intake, water treatment, and waste treatment. Data are scattered, based on isolated samples, and for certain elements, nonexistent.

(*e*) Interproduct and interregional substitutability of production. What are the effects of water shortage on population, employment and incomes, within a given region, and what are the effects elsewhere induced by transfers of activity to other regions?

6. The findings of this report may or may not be wide of the mark when the year 1980 or 2000 is realized. Perfect accuracy of prediction is not needed in order to justify the study, nor was it ever a necessary condition of its success or failure. For one thing, the data and the analytical framework of the study are organized in a way that critical evaluation of the results can take place systematically and continuously, and long-range plans can be modified as needed. Moreover, certain policy decisions can be taken now without fear of serious consequences should the projections be in error. For example, unless storage costs are vastly overestimated and waste treatment costs vastly underestimated, streamflow of satisfactory quality will require an approximate doubling of the amount of organic waste removed from each gallon of municipal and industrial discharge regardless of program. To raise the level of waste treatment by 100 percent can have no serious irreversible effects on stream regimen such as, for example, might result from a doubling of storage capacity. If, therefore, a policy of maintaining stream quality were to be adopted, the necessary steps to assure adequate waste treatment could be taken at any time without fear of the consequences of a later correction in any of the measures.

7. As the intensity of water use relative to available supply increases, the matter of allocating water among uses becomes an integral part of water resource development. The relationships to be discerned between the benefits and costs of increments of control will require an ever-increasing knowledge of long-range economic goals and potentials for the Nation as a whole, as well as for the separate regions of which it is composed. Planning of water use, therefore, will become an inseparable component of general economic planning.

PART II. THE SUPPLY OF AND DEMAND FOR WATER: A METHOD OF COMPREHENSIVE ANALYSIS

Objectives of the study

When the Senate Select Committee on National Water Resources was created by senatorial resolution, it was asked "to respond specifically and factually" to the following questions:

1. How much water development is needed?
2. When is it needed?
3. Where is it needed?
4. What should be the pattern of water development?
5. What levels of cost and expenditures are justifiable for future water development?

In connection with senatorial action on the resolution, a report was submitted to the Senate by Senator Anderson, of the Committee on Interior and Insular Affairs, to which the proposed resolution had been submitted.[1] Senator Anderson's report pointed out that "two important gaps will need to be filled" before the considerable amount of information already available to the Federal Government could be mobilized. These gaps were—

> (1) * * * what amounts of water will be required in relation to various levels of population and economic activity—

and

> (2) * * * the economic limits for water development—that is, what costs per acre-foot are economically justified for water for various uses, and how much expenditure of public and private funds can be economically justified for water programs.

This report provides information designed to fill the gaps in data noted by Senator Anderson and to answer the questions posed by the resolution. However, in spite of pathbreaking collation, research and analysis by Federal agencies, some of the gaps could not be filled and some of the questions remain only partially answered. Since part of the questions remain unanswered not because the facts are unknowable but only because the number of questions asked have exceeded the capacity of existing research apparatus, it is only a matter of time and manpower for the answers to be produced. Certain questions, however, are not so readily solved, even with all the money in the world. Everything pertaining to the future is uncertain, but what pertains to human circumstance and will is much more so.

The most sophisticated analysis of future possibilities that we can achieve is construction of a "model." In this sense of the word a model is not an ideal pattern to which we should conform, but is, in slightly more polysyllabic terms, a hypothetical entity composed of a number of elements whose interrelations can then be studied. The intellectual exercise involved in this activity can have a practical result. If the postulates that are initially assumed are reasonably good guesses of what may be encountered in the future, and if the assumed behavior of the elements agrees with observed behavior, the end result of the exercise is akin to a "forecast." In fact, apart from the intuitive predictions of a well-authenticated prophet, this technique is the only one that is likely to yield persuasive results. At no time, however, should we lose sight of the fact that all results are preordained: they are built into the model in the form of the elements selected for study, postulated quantities, and assumed interrelationships. It is this technique on which the following report rests.

To our knowledge, the present effort of the select committee in conjunction with Federal agencies and departments concerned with water use has evoked studies of greater depth and scope than has been attained by any previous comprehensive investigation. This report serves as a preliminary summary of some of the findings, especially as they are related to the analytical model that is used for projecting water supply and demand to 1980 and 2000.

---

[1] S. Rept. No. 145, 86th Cong., 1st sess.

Method of analysis

Since the validity of any statistical conclusion is inseparable from the method of its determination, a clear understanding of the way in which the data were developed and organized is essential. The description of the methods adopted for the study is divided into the following sections: (1) definitions, (2) geographic unit, (3) projecting the demand for water, (4) estimating the physical supply of water, (5) estimating the costs of supply, and (6) aggregating demand and supply and relating them to each other.

A few definitions

There is enough variability in the semantic practices of writers in the field of water use to warrant a brief glossary.

1. "Withdrawal," "gross use," "intake": These words are used more or less synonymously, although the mental image each connotes may be somewhat different. They refer to the total amount of water that is diverted from a natural water course or body of water into a well-defined hydraulic system such as an irrigation system, factory, municipal waterworks, steam-electric powerplant and the like.

2. "Net use," "depletion," "consumption," "loss": These words are used synonymously. They refer to the disappearance of water from the region as a result of incorporation into a product or conversion to vapor by evaporation or transpiration.

3. "Onsite uses": This term covers the use of water for programs designed to abate soil erosion and maintain soil moisture and for consumption by swamps and wetlands required as wildlife habitat. The term is also used to refer to a subordinate concept. The amount of water used per one-tenth of a square mile of surface area by conserving soil and moisture practices is defined as an "onsite" use. Distinct from "onsite requirements" in this narrower sense, the Soil Conservation Service speaks of "downstream requirements," as the net reduction in surface runoff after account is taken of estimated contributions to ground water aquifers that originate in the "onsite" use. We can consider "onsite requirements," in the narrow SCS sense, as equivalent to a "gross" requirement for soil and moisture conservation and "downstream requirements" as equivalent to "net use."

4. "Flow uses": The term refers to water used within recognized stream channels. Hydroelectric power production has been arbitrarily included as a flow use, although purists object to such classification. Other flow uses are navigation, sport fishing habitat, fresh water discharge into estuarine areas in order to maintain proper salinity, and the disposition and dilution of waste water.[2]

The geographic unit: 22 water resource regions

It was determined at the outset that a detailed study of water use, city by city and project by project, was neither wanted nor possible in the available time. Accordingly, the United States was divided into 22 water resource regions, as shown on map 1 in part I. These regions coincided with the industrial water use regions used in the 1954 Census of Manufactures, with the following modifications: the Missouri region was divided into "Upper" and "Lower" Missouri, to separate the relatively well-watered and the relatively dry parts of the region. For the same reason the Arkansas-White-Red region was divided into "Upper Arkansas-Red Rivers region,"[3] and "Lower Arkansas-White-Red Rivers" region; the "Upper Rio Grande-Pecos" was separated from the "Western Gulf"; and the "South Pacific" was separated from the "Central Pacific." Boundaries for all 22 regions followed county lines that were closest to watershed lines. All data were assembled as aggregates for the region as a whole. Local conditions that differ either in degree or kind from the average of the region are concealed. By slurring over such local variations, however, a cleanly focused picture for each region becomes possible. The deficiencies in this procedure are twofold: (1) conclusions pertaining to the region as a whole cannot be used to determine the merits of a particular water resource project unless its impact is regionwide; (2) no conclusions can be drawn regarding the likelihood, magnitude and cost of projects concerned with long-distance transportation of water within a basin. Another way of viewing this limitation would be to assume that intrabasin location of activity will more or less automatically conform to the intrabasin location of supply. While such automatic response can

---

[2] The classification of uses as "withdrawal," "flow" and "onsite" follows Ackerman and Löf, "Technology in American Water Development," published for Resources for the Future, Inc., by the Johns Hopkins Press, Baltimore, 1959, pp. 47–48

[3] Usually referred to as Upper AWR.

be expected to occur in some degree, we have had enough experience to expect the contrary. A desirable adjunct to regionwide conclusions would be an index of variability in the projected matching of supply and demand for zones within each region. The probable error of any estimate made for a zone would, however, be substantially higher than the probable error of estimates made for regions, since the smaller is the area for which an economic projection is made, the greater is the likelihood the projection will depart from realized experience.

For most questions relating to water a "national aggregate" is of limited value unless it is intended to be a summary statement of results reached region by region. Unlike other mineral resources, the major movements of water are dominated by the forces of nature. For oil, gas, metallic and nonmetallic minerals (except most rock, sand, and gravel), the national market is a useful abstraction, since these minerals move readily by artificial means. Water does not fit this pattern. The overwhelming bulk of it is "used" close to the point at which it initially falls on the earth in the form of rain or snow. Natural land cover, cultivated crops, or direct evaporation into the atmosphere from the surfaces of fields, highways, and rooftops account for two-thirds of average annual precipitation.[4] The remainder appears as stream runoff, having either moved directly across the surface of the land until it reached a water course or first filtered into the ground and into a ground water aquifer that subsequently discharged into a stream channel. The supply of water with which this report is concerned is the total measurable stream runoff and its use by man.

Projecting water use

The way in which the future demand [5] for water was estimated depended upon its use. Except for navigation and hydroelectric power, however, all projections were ultimately related to changes in national or regional population. Population projections developed by Resources for the Future in connection with its study, "Resources in the American Future," [6] were made available to the select committee and participating Federal agencies. These projections were in three series—a high, medium, and low—of which the medium was based upon the Bureau of the Census' series III in its current set of population projections.[7] The high and low series of Resources for the Future straddled by a moderate amount the Bureau of the Census' series I (high) and series IV (low) as a result of adopting slightly different assumptions regarding migration and birth rates. Resources for the Future had also made estimates of gross national product and the output of industrial products by major category consistent with its population estimates. Federal agencies were asked to project the demand for water by region on the basis of these national estimates unless the agency preferred to use others. Whether the projections supplied by Resources for the Future were used or the agency's own projections, the final results were compiled in three series of water demands, high, medium, and low, with major emphasis being placed on the medium.

Since the demand for water is a function of population, production, and the technical relationship between a unit of product and the required water input, accuracy of the final figures cannot be divorced from the accuracy of underlying demographic and production estimates. It is difficult enough to make estimates covering the next 40 years when they apply to the Nation as a whole. The number of uncertainties that intervene for a regional projection, allowing for all foreseeable possibilities of interregional substitution, both as locus of habitat and as locus of production, compounds the difficulties and raises the probability of error by an unknown but undoubtedly formidable factor. Recognizing that this was no place for traditional prudence, all participants in the study proceeded to divide the national totals among regions foreseeing that they might be wrong by the year 1980 not only because of some unanticipated force, but also because their projections could not be reconciled, one against the other, until all had made a tentative stab at it. The fact that projected uses may be incompatible with available supply, and in some instances with each other, is not to be taken as a fault of the projector or a deficiency in the method but as a deliberately sought revelation of the study itself. This report is the first step in a foreseeable sequence of adjustments, and readjustments partly of national but to a greater extent of regional projections.

---

[4] Material supplied to the author by the Weather Bureau and based upon Technical Paper No. 37, "Evaporation Maps for the United States," by M. A. Kohler, T. J. Nordenson, and D. R. Baker, Washington, 1959.

[5] "Demand" is used in a loose sense and not as a schedule of quantities related to prices

[6] Op. cit.

[7] Bureau of the Census, "Current Population Reports," series P-25, No. 160 and later issues.

Preliminary regional population projections were made by extrapolating the change in percent of national population in each region between 1940 and 1950 and applying the resulting new percents for 1980 and 2000 to national totals. Urban population was projected in the same way, except that it was arbitrarily assumed that rural population in the year 2000, medium projection, would be 50 million for the Nation as a whole, the remainder being, of course, urban population. These preliminary regional projections served as the basis for other estimates that required regional population estimates. More refined population projections were subsequently prepared [8] by Resources for the Future on the basis of materials submitted by the Bureau of the Census. Another study scheduled for completion some time in the future will incorporate whatever modification is indicated by the second set of population estimates. The relationships between water supply and demand are not likely to be significantly altered as a result of using the later estimates.

A brief statement of methods used in estimating future water demands for each category of water use now follows.

Municipal water use was calculated as the product of projected urban population and a projected quantity per capita, computed from known trends and from absolute quantities currently used in each region.[9]

Water used in manufacturing, mining and steam-electric public utilities was estimated by (*a*) projecting national output and distributing it among regions, and (*b*) projecting the input of water per unit of product on the basis of experienced and foreseeable technological changes. Totals for each industry were computed by combining the two projections.[10]

Water used in agriculture was estimated for irrigation [11] by distributing national agricultural output among regions, determining the quantity of irrigated acreage, and determining the amount of water required per irrigated acre on the basis of stipulated trends in water use. Quantities of water for farm animals [12] and for rural domestic use [13] were estimated by analogous methods, using a per capita basis—animals and humans—instead of acres.

The foregoing computations yielded withdrawals, i.e. gross use rather than the amount of water lost through evapotranspiration or by incorporation into the product. Since losses turn out to be a significant element of water use, its method of estimation should also be understood. In the case of municipal use there are virtually no well established facts. A figure of 10 percent is encountered occasionally in the literature. This may overstate losses in some communities and seriously understate them in others, stemming from variations in (*a*) temperature and humidity, (*b*) amount of lawn watering, (*c*) amount and type of air conditioning, (*d*) the pattern of industrial uses served by the municipal system, and (*e*) the importance of industrial and public uses relative to residential. Most of the western regions include a number of climatic zones. Because of this fact, variations in the ratio of loss to intake may be as great or greater among cities within a region as are the variations in averages among regions. Fortunately, for an appreciation of foreseeable trends a high degree of accuracy is not equally essential for all withdrawal uses. The amount of water estimated as lost in 1954 from municipal use in the United States as a whole was 2,100 million gallons per day [14] out of an estimated loss of 109,500 million gallons per day for all withdrawal purposes, or about 2 percent. In estimating future municipal losses, it was assumed that eastern regions experienced a loss equal to 10 percent of intake and that western regions experienced a 20-percent loss. These estimates seem to be conservative. In the absence of carefully controlled studies they secure a higher degree of informal expert assent than alternative assumptions.

---

[8] See Committee Print No. 5, "Population Projections and Economic Assumptions."

[9] See Committee Print No. 7, "Future Water Requirements for Municipal Use."

[10] Committee Print No. 8, "Future Water Requirements of Principal Water Using Industries"; Committee Print No. 10, "Electric Power in Relation to the Nation's Water Resources," Report by Federal Power Commission and unpublished materials prepared by FPC.

[11] Committee Print No. 12, "Land and Water Potentials and Future Requirements for Water"; Committee Print No. 14, "Future Needs for Reclamation in the Western States."

[12] Estimated by Karl Gertel, Agricultural Research Service, U.S. Department of Agriculture, unpublished.

[13] Estimated from data in MacKichan, "Estimated Use of Water in the United States," 1955, U.S. Geological Survey Circular 398.

[14] All water figures are given in millions of gallons per day, except where stated otherwise.

Irrigation losses were estimated by the Department of Agriculture on the basis of limited experimental data in conjunction with specified levels of irrigation efficiency assumed for 1980 and 2000. Two variables are involved: (1) the relation between net plant requirements and gross irrigation requirements as a function of "efficiency" of water application, and (2) the quantity of water that is lost as seepage into the ground that ultimately becomes a contribution to ground water. Both of these factors were taken into account, but the difficulties of estimation for a large region are considerable.

Losses from manufacturing, mining and steam-electric power in 1954 were assumed to be equal to the difference between "intake" and "discharge" as measured by the Bureau of the Census.[15] The ratio of loss to intake experienced in 1954 was assumed to hold for 1980 and 2000. Keeping this ratio constant, however, did not necessarily keep the ratio of loss to product constant, since a variation in input of water per unit of product was characteristic of a number of industries.

Census data distinguished between intake of fresh water and intake of brackish water, but made no distinction between discharge of fresh and brackish water. It was assumed that brackish water was used primarily for cooling and sanitation purposes and that losses would be negligible. Accordingly, all industrial losses—manufacturing, mining, and steam-electric utilities—were assumed to be of fresh water. All losses of agricultural and municipal water were, of course, also assumed to be fresh.

It is not possible to appraise the accuracy of intake and discharge quantities compiled by the Bureau of the Census. The figures are based upon questionnaire responses collected from larger industrial users, and although there are virtually no theoretical difficulties in attaining a high level of accuracy (simple metering of intake and discharge by each plant is all that is required), many, perhaps most, industrial users do not measure water intake or waste disposal. In the few industries for which studies for separate plants have been conducted by the U.S. Geological Survey,[16] there are some differences between Census and USGS findings. The fact that losses estimated for 1980 and 2000 are dependent upon the 1954 ratio of loss to intake is another possible source of error. While there is some knowledge of the trend in gross use per unit of output there is no comparable information regarding the rate of loss per unit of product.

In addition to water intake, discharge, and loss for the foregoing withdrawal uses, estimates were made by the Soil Conservation Service of water requirements for land treatment and structures designed to abate erosion, conserve soil moisture, and increase the number of farm ponds.[17] These estimates were provided in two forms: (1) "onsite" requirements, which are analogous to withdrawals or gross use, and (2) "downstream" requirements, which are analogous to consumption or depletion, since they measure the net reduction in stream runoff to be expected over an area of 1,000 square miles. In relating these uses to future supply-demand relationships, it was assumed that up to now these uses of water, whether onsite or downstream, have been reflected in stream runoff measurements (i.e. because of these uses stream runoff has been lower than it would have been), and therefore are not to be charged against stream runoff for 1954. All projected *increase* in "downstream" requirements is assumed to cause a corresponding reduction in stream runoff. Therefore, losses for 1980 and 2000 are computed as the *increase* in evapotranspiration over 1954 resulting from extension of the program.

A similar approach was adopted by the Fish and Wildlife Service[18] in connection with its estimated water requirements for swamps and wetlands serving as habitat for ducks, geese, muskrats, and the like. The projected increase in wetlands was based upon the projected ratio of hunters to population as well as upon the projection of population itself, and the estimated increase in wetland area was designed to keep wildlife population dependent upon wetlands at a constant ratio to the projected number of hunters. Special attention was given, of course, to existing flyways and the known habits of migratory wildfowl. Implicit in these projections is the assumption that the number of ducks and geese is proportional to the extent of habitat.

---

[15] Industrial Water Use Supplement, 1954 Census of Manufactures, Bulletin MC-209, supplement.

[16] See Geological Survey Water Supply Papers 1330-A, 1330-B, 1330-C, and 1330-D.

[17] Committee Print No. 13, "Estimated Water Requirements for Agricultural Purposes and Their Effects on Water Supplies."

[18] Committee Print No. 18, "Fish and Wildlife and Water Resources."

The last category of water demand consists of "flow" uses: a requirement for a given quantity of water within the channels of regular water courses. Uses met in this way are (1) hydroelectric power, (2) navigation, (3) sport and commercial fisheries, and (4) disposition of waste and dilution of waste effluent. The ways in which flow requirements were estimated varied for each use.

Water required for hydroelectric power was estimated by the Federal Power Commission for 1980 on the basis of existing installations and installations planned for the period 1960–80. With existing and anticipated installed capacity given, along with known head and assumed load factors, the quantity of energy and the required amounts of water could then be computed for each region. The 1980 relationship between existing and potential hydroelectric output was then increased for the year 2000 on the basis of a trend considered probable for the 20 years following 1980, and water requirements adjusted accordingly.

Navigation requirements were projected by a comparable method, that is, by a computation of flows required in association with existing and foreseeable navigation projects. One difference between hydroelectric water requirements and navigation requirements lay in the fact that the latter were specified as required for either 12 months out of the year or for a lesser period where ice interfered with navigation, whereas no time period was specified for hydroelectric power. This meant that installed capacity was assumed to be in full use only for the comparatively short period of high flow. During the remainder of the year part of the capacity was assumed to be idle. For both hydroelectric power and navigation, regional aggregates were computed as the sum of the unduplicated flows specified for the region. Total flow requirements could never exceed the actual flow of a region so long as plans were consistent with the region's hydrology. This method of projecting requirements did not necessarily imply that all projected uses, including flow uses, were compatible with each other. It might turn out that by 1980 the projected increase in irrigation would, if realized, so deplete streamflow that projected navigation requirements could not be met. A more detailed discussion of the compatibility of projected uses is found below.

The third flow use consisted of a volume of water, flowing or impounded, to provide habitat for game fish. This requirement was estimated by computing the relationships between population and fishermen, between fishermen and harvest of sport fish, between volume of water and fish harvest. Projected water requirements assumed that the catch per fisherman would fall slightly from present levels but that other elements would be kept proportional to current experience. Water requirements were specified in terms of both instantaneous flow and volume, but the two are not directly interchangeable. Sport fishing is largely dependent on the top 30 feet or so of a lake; increasing volume by increasing depth would not necessarily add to the quantity of fish habitat, nor by implication, to fish population.

Another fish and wildlife flow requirement has been set aside for special, qualitative treatment. This is the requirement for a flow of fresh water into estuaries and other coastal waters in which various forms of useful aquatic life breed and, in the case of shellfish, complete their life cycle. Fresh water flow is the device for controlling the salinity of these critical shoreline waters; a reduction in flow increases the salinity content of water throughout the area in which fresh and salt waters mix. A landward movement of a given degree of salinity can have adverse effects on breeding and living areas, with a consequent adverse impact on aquatic population. Biologists specializing in this field have not been able to complete the studies needed to find out, in relatively precise, quantitative terms, the effects of changes in fresh water flows on the various fisheries dependent upon estuarine waters. There are prospects for improved management of existing fisheries. In projecting 1980 and 2000 needs, therefore, water requirements were kept constant at the prevailing average runoff, relying wholly upon improved technology to meet future requirements. There is ample evidence, however, that total discharge of fresh water will decline between now and 2000, although minimum flows might be raised. In light of these prospects it is necessary to reassess the potential role of technology in offsetting any deterioration in coastal habitat.[19]

---

[19] The Fish and Wildlife Service, U.S. Department of the Interior, has been asked to prepare a supplementary statement on the effects of prospective changes in fresh water flows.

The special case of waste dilution

The final flow requirement is the quantity of relatively clean, well-oxgenated water that is necessary for the dilution of waste effluent. Regardless of the level of treatment given to sewage and industrial wastes, some dilution with good quality raw water is needed. Neither mechanical nor chemical methods of treating large quantities of waste water have been developed to the point where all impurities can be removed by large-scale, practicable techniques. There is, furthermore, an inherent opposition among certain pollutants that raises the strength of one as the other's is diminished by treatment. Pollutants can be conveniently placed into the following classes: (1) organic materials that deplete the dissolved oxygen content of the stream in the process of further decomposition; (2) pollution from plant nutrients such as nitrogen and phosphorus from sources that include the effluent from sewage that has undergone biological treatment. These fertilizers stimulate the growth of algae, which when they die create a demand for oxygen; (3) unchanging and cumulative elements that cause a deterioration in raw water quality. These include chlorides and organic chemicals, "particularly chloroform extractables."[20] A fourth polluting element is heat, which enters the stream with the discharge of cooling water. Heat not only can have directly deleterious effects on desirable stream biota but also can impede the natural regenerative power of a stream to cleanse itself. The two remaining classes of pollutants are bacteria and toxic substances. It was assumed, however, that these lend themselves to satisfactory treatment and would not contribute to the need for streamflow.

In computing waste dilution requirements, gross withdrawals for certain industrial uses indirectly became a part of the analysis.[21] Municipal waste is also a BOD pollutant, and is about equal to industrial waste in quantitative importance for the Nation as a whole. The waste load discharged to the streams was computed as a function of the quantity of waste-carrying water discharged by municipalities and the food processing, pulp and paper, chemical, and petroleum refining industries. This discharge was used as the basis for computing the number of standard units of waste, the "population equivalent," that was being released to surface waters. On the basis of the number of "P.E.'s" per region, keeping municipal wastes and industrial wastes separate for analytical purposes, the quantity of oxygen-consuming effluent that remained after treatment was estimated. The next element in the analysis was to ascertain the degree to which the stream could absorb these BOD substances and not suffer a decline in dissolved oxygen below a critical point, taken for purpose of this study as 4 milligrams of oxygen per liter, a ratio approximately the same as 4 parts per million. The BOD absorbing capacity of a stream is a function of its physical characteristics—temperature, velocity, turbulence, freedom from sediment, length of reach, and depth—and the rate and spacing of the outfall of waste. By properly organizing these elements into systematic formulas it was possible to measure the degree of pollution in a way that allowed for its direct incorporation into the scheme of water demand, namely, as a quantity of water of adequate quality[22] that had to be flowing in the stream in order to assure a dissolved oxygen content of 4 parts per million in the stream.[23]

The quantity of streamflow needed in order to assure adequate dilution of effluent varies with the intensity of BOD-removing treatment. If, for example, treatment removed 80 percent of BOD, the required dilution water would be half the amount needed if only 60 percent of BOD were removed; 90 percent removal would reduce the need for dilution water by half again, and so forth.

With increases in the level of treatment, the effluent from treatment plants contains an increasingly larger quantity of nitrogen and other fertilizers that stimulate algal growth and give rise to a secondary oxygen demand. It is mainly for this reason that high level treatment by known technology cannot reduce dilution requirements to zero. Another reason, and one that would become compelling in the absence of BOD and algae dilution requirements, is the increasing pollution by accumulated substances such as chlorides and organic chemicals.

---

[20] The determination of a method for estimating waste dilution requirements and the estimates themselves are the work of George W. Reid, director of the Bureau of Water Resources, University of Oklahoma, Norman, and consultant to the U.S. Public Health Service. These estimates were reviewed by staff members of Public Health Service in Washington and the R. A. Taft Sanitary Engineering Center, Cincinnati. This discussion is wholly dependent upon a draft of Professor Reid's paper which was later printed as Committee Print No. 29, and on conversations held with Professor Reid and Mr. Melvin Scheidt of the Public Health Service.

[21] Industrial BOD pollution was estimated from the quantity of waste-water discharge. Waste-water discharge is the residual when losses and cooling water are subtracted from total intake.

[22] Either water of runoff quality or water that has been purified by natural or artificial means.

[23] Four parts per million serves as a rough measure of oxygen content that will support desirable aquatic life for at least some part of the life cycle. Six parts per million is considered necessary for breeding and normal activity under normal circumstances. We can interpret measures based upon 4 parts per million as reflecting a higher dissolved oxygen content for parts of the region at the expense of a lower content for other parts.

An aside on the relative importance of the latter class of pollutants is in order at this point. On the basis of a preliminary investigation, it was determined that if proper dilution for BOD or algae were provided, the need for diluting chlorides, organic chemicals, and similar pollutants would be met. It was further assumed that discharge of toxic elements would be prohibited. Pesticides and herbicides that reach the streams from land surfaces present a problem the magnitude of which is yet unknown and for which no special provision was made in computing waste dilution requirements.

The dissolved oxygen content of water varies inversely with temperature. Minimum streamflow requirements were computed on the basis of maximum summer stream temperatures that are now encountered. It is assumed that if the heating of surface waters becomes so great as to jeopardize usability of the stream, devices to cool the discharge to heat levels now experienced will be required. No estimates of the probable degree of heat pollution have been made nor have the costs of cooling towers or ponds been included in the cost of waste treatment.

Since the special cases of toxic elements from industry and heat pollution were assumed to be controlled by compulsory use of inhibiting devices and since little is yet known of the effects of pesticides, herbicides, and detergents that reach the streams from land surfaces, the ruling elements in dilution requirements were made dependent on BOD and algae. Whichever of these required the greater flow was considered to be the ruling requirement.

The demand for dilution water is not only a function of the level of treatment but also of the quantity of dissolved oxygen that is to be in the streams. Once the computations are made for a dissolved oxygen content of 4 milligrams per liter, it is a simple matter to estimate the dilution requirements for higher or lower dissolved oxygen contents.

As with all other components of demand, the values were designed for the region as a whole. Stream quality at a particular point will depart from the regional value if, for example, the characteristics of a particular stream differ from the average values that were adopted.

An element of estimation making it likely that the computed flow requirements are conservative stems from the assumption that waste discharge is proportional to the regenerative capacity of the stream. It is the self-rehabilitating characteristic of running water that made it especially difficult to incorporate pollution systematically into the same framework that was available for other uses of water. Running water is continuously subject to reaeration. This means that some oxygen demand can be present at any time without harmful effect on fish life if the rate of aeration exceeds by an adequate margin the rate of oxygen consumption. In other words, subject to appropriate qualification, a stream has a natural waste-carrying power compatible with other uses that depend on relatively clean and esthetically satisfying water. If organic waste is discharged at one point and no further outfalls take place along the downstream stretch, after a certain period of time has elapsed the process of decomposition will have been completed and the normal oxygen content of the stream restored.[21] This means that the pattern of waste discharge could be such that some parts of a stream were always deficient in oxygen for the maintenance of sport fish whereas other parts of the same stream, above or below the deficient area, could support such life. In order to cope with the wide range of indeterminacy introduced by the location factor, it was assumed that the pollution load was distributed in proportion to flow. To the degree that this condition would not be met in reality, the dissolved oxygen content of streams would depart from computed levels. While the assumption of proportionality might be contrary to what is now known of any region, it need not be concluded that the assumption will be equally in error for the year 2000. It is quite conceivable that in the interests of minimizing water deterioration, a form of river basin zoning related to pollution abatement might be adopted throughout extensive reaches of a river or over an entire basin.

---

[21] See A. F. Bartsch and W. M. Ingram, "Stream Life and the Pollution Environment," "Public Works," reprint, date not given

The physical supply of water

The facts of physical supply were developed by the U.S. Geological Survey [25] in the form of several relationships applicable to each of the 22 regions. Additional flow-frequency data for a selection of metropolitan areas and headwaters of navigable channels were also prepared.

Data on stream characteristics were incorporated into the formulas used to ascertain the waste-disposal capacity of the region and waste-effluent dilution flow requirements. The characteristics for which measurements were prepared were (1) mean velocity, (2) average stream length, (3) mean depth at mean velocity, (4) mean flow at mean velocity, (5) chemical quality, and (6) temperature. Chemical quality measurements of the ratios of phosphorus to dissolved solids, nitrogen to dissolved solids, and chloride to dissolved solids were computed. Temperature measurements were prepared from isotherms of the mean monthly temperature of surface water in July and August.

A methodological issue that demanded early decision was the definition of water supply from the physical point of view. The fact that it was decided to define supply as "surface runoff" has already been mentioned. A further word or two will be helpful in understanding why other alternatives were considered but abandoned. At least two such alternatives are possible: (1) A measure of water supply as the annual average yield from precipitation, and (2) a measure of water supply that included ground water and soil moisture inventories.

Undoubtedly there are questions for which either or both of these alternatives are more meaningful than the definition finally adopted. Each was considered and abandoned in light of specific limitations for the project at hand. The first definition would not have served any end of special value unless it were possible to incorporate another variable; namely, a change in the ratio of runoff to precipitation as a function of specified physical actions. Unless this were possible, all significant variability in water supply would emerge as changes in runoff. Once the historical relationship between precipitation and runoff had been presented, there was little further that could be done by way of analysis related to policy on the basis of present knowledge. This does not mean that a similar conclusion need be reached sometime in the future. Should continued research reveal that the ratio of precipitation to runoff can be modified, a broader definition of supply will become meaningful for studies such as this.

A similar reason lay behind the exclusion of ground water and soil moisture from the definition of supply.[26] Reasonably comprehensive knowledge of the location, origin, quantity, and behavior of ground water, such as we have of surface water, is not yet available. It would not have been possible to have treated ground water as systematically as we have been able to handle surface water.

Another reason for ignoring ground water arises out of the fact that in general it is interrelated with surface water in such a way that depletion of surface water ultimately reduces the supply of ground water (by reducing streambank recharge as stream levels fall) and depletion of ground water ultimately reduces surface flow (by reducing the rate of discharge from ground water aquifers). In some valleys the relation between streamflow and ground water reservoirs is so intimate, e.g., the Rio Grande Valley in New Mexico, that ground water pumping can deprive holders of surface water rights of the water to which their rights entitle them.

In spite of knowledge that in the long run surface and ground waters are interdependent, we shall have achieved a major forward step in our knowledge of water supply when we know precisely the forms and magnitudes of interaction for each hydrologic system in the United States. When we have this knowledge we can more rationally plan for overdrafts on ground water reservoirs than is now possible. We shall also be able to integrate ground water storage with surface water storage, toward the dual ends of maximizing usable yield and minimizing costs of regulation. Should these ends prove to be mutually hostile we can at least select the one that is more compelling, knowing how much of the other we must sacrifice.

---

[25] See Committee Print No. 3, "National Water Resources and Problems," for some of the data prepared for the project. A special expression of thanks is owed to Mr. Roy E. Oltman of the Geological Survey for the great assistance which he rendered to the study, not only by preparing so much of the basic hydrological data but also for services generously rendered as consultant and adviser. Neither he nor anyone else other than the author, however, is responsible for errors that might still be found in this report.

[26] By implication a net change in soil moisture attributable to land treatment programs has been incorporated as a change in the demand for water. See discussion and measurements of demand under heading of "Land Treatment and Structures." In a few basins, the program is shown as contributing to supply. For details see Committee Print No. 13, op. cit.

Having decided to measure supply as surface runoff, the next decision was the form which such measure should take. It was decided that the most useful measurement was a flow-duration curve indicating for each region the quantity of flow that is equaled or exceeded a specified fraction of the time. Tables were prepared showing the flow equaled or exceeded 95, 90, 80, 70, and 50 percent of the time.[27] Flow data were computed in units of cubic feet per second and millions of gallons per day. The flow equaled or exceeded 95 percent of the time was then treated as the present minimum flow. For seven regions, upper Missouri, upper AWR, upper Rio Grande-Pecos, Great Basin, Colorado, Central Pacific and South Pacific, where current depletions are relatively large, tables were prepared showing the flow-frequency relationships for flows *after* depletion—i.e., streamflow "still available"—as well as for flows before depletion. The average flow was also computed, as average supply still available and as average supply before current depletions.

"Average supply" is the long-time average annual runoff converted to a rate of flow per unit of time: millions of gallons per day or cubic feet per second. It is this quantity that indicates the maximum amount of runoff produced within a region on a long-run, sustained-yield basis, and is the theoretical limit to which a region's water supply can be "developed."

The term "developed," as used in a hydrologic context refers to the degree of control that can be achieved over a region's water resources. Since both precipitation and streamflow vary seasonally, annually, and perhaps secularly, unless reservoirs are constructed to hold back high flows for release during periods of natural low flow, the supply available for use will follow the periodicity of nature. The range of natural variability is different for different parts of the United States. For this reason, the quantity of storage needed to regulate flow relative to the magnitude of flow also varies for different parts of the country. In order to make possible a systematic treatment of flow regulation, the Geological Survey determined the quantity of storage that would be necessary if flows now available 95, 90, 80, 70, and 50 percent of the time were to be assured 100 percent of the time. In a supplementary study included as an appendix to this report the Survey determined the higher flows available for lower frequencies from the aforementioned storage designed to assure yields 100 percent of the time.

A table was prepared showing the quantity of reservoir capacity in each region as of 1954, and supplementary measures of median depth, median capacity, and total surface area were also prepared. The way in which the facts of flow, storage, changes in minimum flow as related to changes in storage, and total capacity now in place were utilized is described below. Before proceeding with that discussion, however, we shall briefly describe one other major piece of our jigsaw puzzle: the method by which costs of storage were estimated.

Total costs of storage

Costs of storage vary in accordance with nonengineering factors such as the price of land and the costs of relocating people and capital facilities and with engineering factors such as character of the site, capacity of the area behind the dam and technology of dam construction. Preliminary investigation of historical data revealed no clearly established trend over time in costs per unit of capacity. Forces contributing to a secular increase in unit cost growing out of exhaustion of superior sites or necessity for utilizing more expensive land were either concealed by inadequacies of accounting techniques or were offset by declines in cost resulting from technological advances in dam construction. Variability in unit costs among reservoirs could, however, be clearly ascertained as a result of differences in capacity of the reservoir and differences in the physiography of sites in which reservoirs were constructed. For each physiographic variant, nine in all, a separate cost curve was constructed relating cost per acre-foot of storage capacity to size of reservoir.[28]

---

[27] See Committee Print No. 3, op. cit. Not all data prepared by the Geological Survey for this study have been published.

[28] The curves relating costs of storage construction per acre-foot to physiographic zones and size of reservoir, and the map of the United States showing the boundaries of the physiographic zones were prepared by Howard Cook of the Corps of Engineers.

It is hoped that Mr. Cook's other duties will enable him to complete research on the important question of the availability of reservoir sites for river regulation, so that the results can be substituted for the synthetic schedules described below.

Curves relating costs of storage per acre-foot were prepared by Mr. Arnold Babb of the Bureau of Reclamation for western regions. As the reader will see, the Cook curves are averages for a physiographic zone and the Babb curves are averages for a water resource region. At the time of this writing, there were still some questions relating to the composition and measurement of items that went into each set of curves, so that the way in which they could be related to each other had not yet been settled.

It was also apparent from a preliminary survey of file materials that knowledge of reservoir sites has been accumulated by construction agencies with various purposes in mind, but that without additional research in the field and at the desk, an authoritative schedule showing increments of available storage capacity for regulation of flow could not be constructed. Without such a schedule, valuable information relating costs to size by physiographic region would be wasted. Accordingly, a schedule of such reservoir sites was synthesized by the following method: a frequency distribution of reservoirs now in existence[20] was constructed by capacity class; the distribution was then revised to smooth out gaps and to eliminate capacity at the extremes. This was done on the following grounds: (1) the 1954 tabulation includes reservoirs for all purposes. If regulation of water supply on a regional basis had been the objective of building reservoirs up to now, it is likely that many of the smaller ones would not have been constructed, especially where evaporation losses would be excessive; (2) it was assumed that most, and perhaps all, of the best sites have been used. Since "best" is partly a function of size, no reservoirs of the largest size class, 10 million acre-feet and over, was included in the revised distribution. Thus, the 1954 distribution was used as an approximate guide for the future, but with modifications induced by the fact that water supply purposes would dominate future construction and that a greater regularity in the size-class distribution would emerge as total reservoir capacity was increased.

A further modification of the frequency distribution was required when a water resource region was unevenly divided between two or more physiographic zones. It would have made no sense, for example, to assign 50 percent of total capacity to reservoirs of 7 million acre-feet if total capacity for a physiographic zone in a water resource region was estimated at 2 million acre-feet (equal, say, to 10 percent of the total capacity of 20 million acre-feet for the water resource region as a whole). With the total quantity of reservoir capacity distributed by size-class and physiographic zone, it was then possible to use the estimated cost-size relationships for the construction of cost schedules.

The cost curve of storage was prepared for each water resource region on the basis of foreseeable maximum regulation needed. In most regions this meant a supply curve that would supply the maximum amount of regulation that was possible. In five regions—Southeast, Ohio, Lower Missouri, lower AWR, and Pacific Northwest—the maximum storage conceivably needed by 2000 was far enough below the theoretical attainable limit that a lower figure was used. Where a water resource region included two or more physiographic regions, the percentage distribution of capacity based on the 1954 distribution was used only for the share of the dominant physiographic region; a different percentage distribution was arbitrarily adopted to fit the residue of capacity assigned to the one or more physiographic regions that remained.

By combining the schedule of storage increments and the costs of each increment for all physiographic zones in a water resource region, a single supply curve in the form of cumulative capital costs of construction related to cumulative storage was constructed for each of the 22 water resource regions. The upper AWR can be used to illustrate the method that was used. Data are taken from the map and tables in part III. (See map 6, charts 1 and 2, and tables 32–42, inclusive.)

It was readily apparent that by the year 2000 maximum runoff in the upper AWR might be required. The first step, therefore, was to plot the following points on double-log paper showing the amount of storage needed to assure the designated flow 100 percent of the time:

Upper Arkansas-White-Red:

Flow	*Storage*
640 million gallons per day (now available 95 percent of the time).	420,000 acre-feet.
1,070 million gallons per day (90 percent).	700,000 acre-feet.
2,000 million gallons per day (80 percent).	1,200,000 acre-feet.
3,200 million gallons per day (70 percent).	2,000,000 acre-feet.
6,800 million gallons per day (50 percent).	5,300,000 acre-feet.
13,000 million gallons per day equals average flow.	

When this line was extended continuously from the last two plotted points to the average flow, 13,000 million gallons per day, it indicated that storage of 13 million acre-feet was required.

The next step was to determine the percentage distribution of total capacity by size class and the distribution of total capacity between physiographic regions. By reference to the map of physiographic zones it was seen that 90 percent of total capacity was assigned to zone H, amounting to 11,700,000 acre-feet, and distributed in accordance with the adopted percentage schedule:

---

[20] As of 1954. See U.S.G.S. Water Supply Paper 1360-A, "Reservoirs in the United States," by Nathan O. Thomas and G. Earl Harbeck, Jr.

Zone H—Total storage, 11,700,000 acre-feet

Size class (thousand acre-feet)	Percent distribution		Capacity of class (thousand acre-feet)
	Actual, 1954	Revised	
7,000	68		
3,000	0	30	3,510
1,500	0	20	2,340
700	7	20	2,340
300	12	16	1,872
150	4	5	585
80	4	4	468
50	2	3	351
30	1	2	234
10	2		
Total	100	100	11,700

Ten percent of the region's capacity was assigned to physiographic zone C and distributed as follows:

Zone C—Total storage, 1,300,000 acre-feet

Size class (thousand acre-feet)	Percent	Capacity of class (thousand acre-feet)
7,000		
3,000		
1,500		
700		
300	30	390
150	30	390
80	10	130
50	10	130
30	10	130
10	10	130
Total	100	1,300

The next step involved computation of storage costs by size class in each region. Costs per acre-foot were taken from the appropriate cost curves of chart 1 (p. 60).

Size class (thousand acre-feet)	Zone H			Zone C		
	Cost per acre-foot	Capacity of class (thousand acre-feet)	Total capital cost of class (millions)	Cost per acre-foot	Capacity of class (thousand acre-feet)	Total capital cost of class (millions)
30,000	$10			$28		
7,000	14			40		
3,000	18	3,510	$63.2	49		
1,500	24	2,340	56.2	56		
700	30	2,340	70.2	66		
300	40	1,872	74.9	80	390	$31.2
150	50	585	29.3	95	390	37.1
80	62	468	29.0	110	130	14.3
50	73	351	25.6	120	130	15.6
30	86	234	20.1	135	130	17.6
10	120			180	130	23.4
Total		11,700	368.5		1,300	139.2

Finally, the two physiographic zones were aggregated into a single schedule, and capital costs were converted to annual costs of operation, maintenance, and amortization.

Upper Arkansas-White-Red: Zones H and C

Size class (thousand acre-feet)	Capacity of class (thousand acre-feet)	Capital cost of class (millions)	Cumulative capacity (thousand acre-feet)	Cumulative capital cost (millions)	Annual cost by class (millions)	Cumulative annual cost (millions)
3,000	3,510	$63.2	3,510	$63.2	$2.8	$2.8
1,500	2,340	56.2	5,850	119.4	2.5	5.3
700	2,340	70.2	8,190	189.6	3.2	8.5
300	2,262	106.1	10,452	295.7	4.8	13.3
150	975	66.4	11,427	362.1	3.0	16.3
80	598	43.3	12,025	405.4	1.9	18.2
50	481	41.2	12,506	446.6	1.9	20.1
30	364	37.7	12,870	484.3	1.7	21.8
10	130	23.4	13,000	507.7	1.1	22.9

Capacity and costs can be rearranged to yield marginal costs and average costs per acre-foot of storage. By ascertaining the water yields from storage, all costs can be computed as a function of flows.

A final adjustment, not accomplished until the estimate of needed storage capacity was made, was a subtraction of storage losses from reservoir yields and a redetermination of required storage capacity.

Integration of supply and demand: Physical

In this section we shall show how the various elements of demand were aggregated where aggregation is meaningful, and how they were treated as complementary uses where aggregation is misleading. We shall then show how the resulting measure of demand was related to supply, treating both sets of magnitudes as physical quantities. In the next section we shall introduce economic magnitudes.

Our method requires that (1) depletions from the basin be aggregated and "charged against" surface runoff. (This conforms to our assumption that evapotranspiration losses disappear from the region.) (2) Flows capable of satisfying more than one use must be compared with the largest flow requirement. If the largest requirement can be met all lesser requirements presumably can be met, provided water quality is equal or superior to the highest quality standards demanded by any of the uses.

Measurement of "demand" and its relation to "supply" are comparatively straightforward problems so long as they refer to a particular reach of stream within which uses are identified by location and by quantity. If points of use can be specified, the available water can be routed from point to point and the adequacy or inadequacy of flow and quality readily ascertained. When, however, we generalize for a region as a whole, within which we cannot specify the precise location of the various uses projected 40 years hence, an entirely different method of relating demand to supply must be adopted.

A major indeterminate element in a regional measure is the fact that gross use—i.e., the sum of withdrawals, onsite uses and flow requirements—can vary over a very wide range relative to supply. This indeterminacy stems from the fact that water is capable of reuse. Depending upon the nature of use, treatment given to waste water, distances between points of intake and discharge, and variability of flow, temperature, depth, and velocity of the water in the stream, the number of times of reuse may range from none or once to many times.

Indeterminacy is displayed on a small scale by the variation in water intake per unit of product within a single industry by different plants. One plant may practice no recirculation; another may treat its cooling and process water moderately and purge it after it has been recirculated once or twice; a third may adopt such intensive treatment and recirculation that practically no water is discharged once it is taken into the plant. A comparable variability of gross use relative to intake can be extended to a region and to all of the uses to which its water supply can be put. Recirculation within a plant reaches its limit when (*a*) the water originally taken in as a result of successive use, reuse and treatment is exhausted to the atmosphere in the form of vapor, or (*b*) in spite of maximum treatment, water quality has deteriorated beyond repair and usability. At this point the plant must discharge the unusable water and replace it with new water of higher quality. Thus the elements of (*a*) loss through evaporation, and (*b*) deterioration beyond the point of rehabilitation serve as determinate limits to which a given quantity of water can be put. These are the boundaries of use that have been adopted for a region. The boundaries have empirical content if (*a*) the loss through evapotranspiration can be estimated, and if (*b*) a minimum usable quality can be stipulated along with specified levels of waste treatment. If it can also be shown that with existing and foreseeable technology there are limits to waste treatment, and if, when this limit has been reached, a flow of specified size is needed to assure the region of the usability and reusability of its water supply, the sum of water lost to the atmosphere plus the quantity of water that must be flowing in the region's streams for quality maintenance purposes fixes the limit of water use within a region. By implication the limit of water use fixes the level of population with a given pattern of economic activity that the region's water supply will support.

Diurnal, seasonal, and annual variability of both demand and supply poses special problems of analysis. In order to compose these differences with a minimum of difficulty it was decided to convert both demand and supply into daily averages, i.e., total annual requirements or runoff, as the case may be, divided by 365. Usefulness of an average daily measure is not unduly impaired by seasonal fluctuations except in specific instances. The most extreme seasonal variability of use is found in agriculture. An exploratory survey[30] for various basins indicated that the variability of need was so related to the variability of flow and natural storage that in some regions the concentration of irrigation demand into 4 months would require no more and perhaps even less storage than if the same annual water demand were spread evenly over the year; in other basins more storage would be required. In view of this fact it was decided that no substantial increase in accuracy would be gained by adding a factor to account for concentrated requirements during a part of the year. Furthermore, once the streams were subjected to regulation beyond a certain degree, the quantity of storage would be large enough to allow for some variation in daily or weekly release in accordance with variation in demand. It should be understood, however, that in particular situations a seasonal variability that exceeds a particular magnitude would require more storage than the same total quantity of water differently used over a long period of time. Hydroelectric power requirements, to cite a slightly different situation, may vary diurnally to such an extent that "pondage" is required at the site of power production even if larger regulatory reservoirs are in operation on the stream. No requirement for pondage has been included in the estimates of required storage.

---

[30] By Roy Oltman, U.S.G.S.

The addition of losses from runoff to waste dilution—i.e., quality maintenance—requirements served as the measure of required flow in the region. At first it was intended that the required flow for any region be specified as the sum of losses plus the greatest of the various flow requirements: navigation, hydroelectric power, fish habitat, required estuarine discharge, or quality maintenance. Requirements for hydroelectric power, however, could not be stipulated in terms of minimum flows, since variability of flow has generally been assumed to be an inevitable condition of hydroelectric power production. Sport fishing habitat would not serve as a guide for determining minimum flows because there is some substitutability between habitat in streams and habitat in lakes. By increasing suitable reservoir habitat it would be possible to reduce the demand for flowing water. Minimum discharge into estuaries might have served as a basis for stipulating minimum flows, except for the fact that the present variability is already taken for granted. Navigation flow requirements should properly be considered as fixing the lower limits of flow and were tentatively adopted as determining, when added to losses, the "required flows" for several regions. It was decided, however, to limit the measure of the "required" or "ruling" flow to losses plus quality maintenance flows for the following reasons: (1) navigation requirements would have been ruling only in a few regions and only for the higher levels of waste treatment; (2) by building low dams and locks, navigation flow requirements can be sharply reduced; (3) navigation requirements fall within the range of required quality maintenance flows for various levels of treatment for all regions except lower Missouri.

The addition of evapotranspiration losses to waste dilution requirements served as the "measure" of potential water requirements in each region. If expected daily flows were to fall below the required amount but still be greater than losses, we could conclude that quality of water in the streams would fail to meet stipulated standards during the period of deficient flow. For example, required flow for New England in 2000, medium projections, is estimated at 19,500 million gallons per day with 97½ percent treatment of municipal and industrial wastes and an intraregional distribution of waste discharge proportional to flow. This figure can be compared with present availability of flow and a determination made of its adequacy. From our data on availability of flow we see that with present storage a flow of 16,000 million gallons per day is available 80 percent of the time and a flow of 22,000 million gallons per day is available 70 percent. An approximate interpolation, therefore, indicates that 19,500 million gallons per day is available 75 percent of the time. This means that in a year of average runoff, streamflow would not be great enough to yield water with regionwide average dissolved oxygen content of 4 milligrams per liter for a period of 3 months. For further analysis, potential dilution requirements for lower oxygen contents can be compared with flows of other frequencies. A dissolved oxygen content of zero would require a flow of approximately five-ninths the flow needed for 4 milligrams per liter, or about 11,000 million gallons per day. This quantity of water is available somewhat less than 90 percent of the time. We can conclude, therefore, that under existing conditions of storage by the year 2000, under assumed conditions of production and waste treatment, it would not even be possible to maintain aerobic conditions all the time, let alone a dissolved oxygen content of 4 milligrams per liter. For somewhat more than a month of an average year the oxygen of the region's streams would be completely exhausted, natural decomposition of organic materials remaining after 97½ percent treatment would not take place, and streams would be carrying large quantities of putrescent waste.

The next step in our analysis is to ascertain how much storage would be required for a minimum flow of 19,500 million gallons per day. Since average supply for New England is 67,000 million gallons per day, we know that a flow for four parts per million of dissolved oxygen is well within the capacity of the region. From flow-storage relationships we see that if 4,200,000 acre-feet of storage is added, minimum flow (without regard to losses from storage) would be 16,000 million gallons per day; storage of 7,300,000 acre-feet would raise the minimum flow to 22,000 million gallons per day. Since the required flow is approximately between these two points, an approximation of required storage would be 5,750,000 acre-feet. (A moderate addition to total storage capacity would be required to offset reservoir losses. In some regions of the arid West, as reservoir capacity is added to raise minimum flow, a point is reached beyond which additional reservoir losses exceed the addition to minimum flow.)[31]

What can be concluded if a minimum flow of 19,500 million gallons per day is provided? First, all evapotranspiration losses will be adequately accounted for, since they are projected as only 2,500 million gallons per day. Second, with treatment of waste at 97½ percent, the requirement for dilution water is 16,900 million gallons per day.[32] A flow of 19,500 million gallons per day will leave 17,000 million gallons per day flowing in the streams after losses; hence the oxygen content will be 4 milligrams per liter if 97½ percent of BOD is removed from the waste. Although total withdrawals for all withdrawal uses are projected at 31,300 million gallons per day, reuse is assumed to be possible with ordinary treatment of water since the dilution flow not only meets dissolved oxygen requirements but also provides enough water to offset algal growth and dilution of chloroform extractibles, chlorides, and other accumulative pollutants. There still remain the following questions: (1) Will storage allow for expected diurnal, weekly, and seasonal variation in required flows? (2) Are onsite requirements—land treatment, swamps, and wetlands—met? (3) Are other flow requirements met?

The answer to the first question—possibility of variation in demand around an average daily requirement—is a tentative "yes." Only a specific study of the hydrologic characteristics of each subbasin can yield an authoritative answer.

Whether or not land treatment and structure uses will be met with a minimum flow of 19,500 million gallons per day involves the same question. Gross requirements for onsite uses, as shown in part III, are about 1,000 million gallons per day for the year 2000, of which 800 million gallons per day is lost to the atmosphere. Since losses in 1954 were about 300 million gallons per day, only the increment, or 500 million gallons per day, will have to be met out of existing runoff. Total losses of 2,500 million gallons per day, for all uses, include this 500 million gallons per day. The remainder of onsite water requirement, 500 million gallons per day, since it is not permanently retained on the land, can be treated as a withdrawal use and assumed to be met by recirculation within the region, as in fact it would be if the minimum flow were low enough. Swamp and wetlands consumption is included in the figure for total losses. By maintaining water quality, gross requirements in excess of loss are assumed to be met by intraregional recirculation.

Flow requirements in New England are for hydroelectric power and fish and wildlife habitat. It was estimated by the Fish and Wildlife Service that a flow of water equal to 12,900 million gallons per day would provide the projected quantity of habitat provided the water were of suitable quality; temperature for cold water fishery was not to to exceed 66° F. and for warm water fishery not to exceed 81° F.; oxygen content was stipulated as 5 parts per million[33] and 6 parts per million for warm and cold water fisheries, respectively.

The minimum flow of 19,500 million gallons per day less 2,500 million gallons per day to account for losses leaves a quantity flowing in the streams beyond that required for sport fishing. There remains, therefore, only the matter of quality, since the dilution requirements are specified only for an oxygen content of 4 parts per million and nothing has been stipulated regarding temperature. If during the period of high temperatures and low flow an oxygen content of 4 parts per million is average for the region, the actual distribution of water supply might be as follows: 60 percent water of 6 parts per million, 40 percent of 1 part per million, weighted average 4 parts per million. Should such a distribution prevail, the quantity of water in the streams net of losses with an oxygen content of 6 parts per million would be equal to 17,000 million gallons per day × 0.6 = 10,200 million gallons per day. Hence, all except the habitat equal to 2,700 million gallons per day (12,900 million gallons per day minus 10,200 million gallons per day), would be met by flowing water of adequate oxygen supply. The remaining need would be satisfied if the stipulated flow, when converted to an equivalent volume, is shown to exist within the region. Since New England is well endowed with desirable lake habitat, there is no need for further computation on this score. In some regions, however, it would be necessary for expert opinion to render a judgment on the degree to which lakes and reservoirs would meet sport fishing requirements beyond the capacity of suitable flowing water.

---

[31] See Walter Langbein, "Water Yield and Reservoir Storage in the United States," Circular 409, USGS, 1959.

[32] Streamflow requirements for quality maintenance are also referred to as "dilution water." It should be recognized, however, that the amount stipulated is total streamflow and not merely a dilution added to waste discharge.

[33] Approximately the same as 5 milligrams per liter and 6 milligrams per liter, respectively.

In computing quality maintenance flows, it was assumed that minimum flows were fixed by waste dilution requirements during the most adverse time of the year, i.e., the period of low flows and high temperatures. It will be assumed throughout this report that if the maximum temperature of streams and lakes were raised beyond the levels now experienced in waters that are needed and otherwise satisfactory as habitat, requirements for use of devices to cool water prior to discharge would be imposed. For complete incorporation into our framework of analysis, it is necessary to estimate the volume of cooling water that would require treatment in cooling towers or spray ponds, the temperature change that would have to be effected, the change, if any, in rate of loss from that already estimated, and the cost of treatment.[34] If complete recirculation of cooling water were required, so that purge were zero or negligible, heat pollution of surface water would no longer be a problem.

There remains the water required for hydroelectric power.[35] A study of the way in which water for hydroelectric power is currently used indicates that capacity is usually installed for a level of flow equal to or in excess of the average flow.[36] If total annual flow after subtracting annual losses is equal to the quantity of water stipulated by FPC as being required in the year 2000, we can assume that hydroelectric requirements will be met unless the load factor were to be unreasonably low.[37] Even if flow minus losses were less than the water needed for hydroelectric power, it is possible for hydro requirements to be met if power installations are located above the areas in which the depletions occur. In order to ascertain this relation, however, the region must be subdivided into smaller units for each of which a separate determination of water supply and demand is made. The need for such a subdivision is apparent for all western regions, with the possible exception of the Pacific Northwest.

By estimating losses and adding waste dilution requirements to them we can readily ascertain whether all withdrawal uses, onsite uses and flow uses can be met with, and in some cases without, further specification of the location of use within the region. Since the storage required for regulation of flow will, in many cases, be adequate for controlled variation of release above and below the stipulated minimum, we can assume that the indicated storage will meet irrigation, municipal, and industrial seasonal needs. Many instances where this assumption will prove to be in error will, of course, be encountered. How serious the error might be, if, indeed, there would be any, cannot be ascertained without further study.[38]

A result of the study that was generally anticipated was confirmation of the fact that some regions do not have the water needed for projected demands in 1980 and 2000, no matter how high a level of waste treatment might be adopted. Some regions will not even have enough water to offset losses, let alone a supply for waste dilution. Since no more water can be used than is available, the implication of such projected shortage is clear: Unless there is a change in technology that would change the rate of water use per person or per unit of product, projected levels of population, agriculture, wildlife propagation, and industrial activities will be impossible of realization for some regions. Adaptation to the limited water supply may take place by following a path that leads to a different *pattern* of water use or by a path leading to pro rata reductions within the projected patterns. Both interregional and intraregional adjustments are likely to be required. Although this phase of the study deserves further refinement, it seems as though two kinds of effects can be anticipated; by making certain adjustments, intraregional as well as interregional, all projected national goals can be met. Different adjustments however, will imply the need for accepting a different *national* pattern of consumption from that which was projected, as well as different patterns within the water-short regions.

---

[34] It is expected that these estimates will be made for a future RFF publication. The necessary information is not now available.

[35] It will be noted that there is no discussion of water for navigation or for commercial fisheries. Navigable channels in New England do not extend beyond tidal reaches; hence there is no requirement for navigation. Commercial fishery requirements were stipulated as being equal to the runoff of 1954. It is seen that by the year 2000 average daily runoff would be reduced by about 2,500 million gallons per day—the amount of loss through evapotranspiration for the medium projections of population and economic activity—but minimum runoff would be raised as a result of waste dilution flows.

[36] The precise amount of installed capacity at any point or within any region will depend upon a number of variables, including hydrology, available head, regional load factor, relative costs of thermal and hydro in the baseload, and relative costs for peaking.

[37] This is equivalent to saying that if average daily flow minus average daily losses is equal to or more than average daily hydroelectric requirements, these requirements are being met regardless of the seasonal variation of water flow.

[38] Storage required for flood control has not been considered. As the degree of regulation to raise minimum flow increases, the need for single-purpose flood control structures decreases. Further study is needed to determine precise relationships in each region.

It would, however, be unrealistic to assume that technical advances in water use will not be realized. Granting this, it still remains true that the precise form which the sum total of adjustments will take, and their relation to aggregate social welfare, will depend upon a rather complicated set of forces such as: Government policies to raise, lower, eliminate, or introduce subsidies; interregional and interindustry mobility of prices and factors of production; relative degrees of monopoly power in factor and product markets; tastes; level and distribution of income; taxes; interest rates; impact on regional incomes, the interests of the region, and the degree of regional control over water use that can be exercised in regional vis-a-vis national interests. In view of the present imperfect state of economic art and knowledge it would be a rash and naive exercise to predict for the year 1980 or 2000 what the outcome of these forces might be. A few limited observations, however, within appropriately narrowed contexts will be attempted in part III of this report.

The impact of impending water shortage serves to emphasize a need for discovery of new ways of using water as well as new ways for avoiding the use of water. It is likely that we have scarcely begun to study the technological possibilities of meeting a growing scarcity of water, since most research effort has hitherto been directed toward meeting other forms of technical and economic constraints. Just as it would be rash to predict the outcome of purely economic forces, it would be equally hazardous to predict the range of potential developments in techniques of water use once a serious program of physical, engineering, and biologic research were begun.

Integration of demand and supply: Economic

The economic end product of our analysis is limited to the relationships that are critical for a large region. Purely local treatment and pumping costs are ignored, since they can be construed as "constants," i.e., as costs that must be incurred even if there is no change from the present in the availability of water of the quality that now prevails. Our economic measures, therefore, are limited to (1) costs of domestic and industrial waste treatment that must be incurred in order to prevent an overburdening of the waste-carrying power of our streams; (2) costs of maintaining the minimum flows that are required if all uses are to be compatibly met to the extent permitted by total runoff after adjustment for losses.[39]

A table was constructed which showed the variation in dilution requirements for each level of treatment for each region. Treatment levels ranged from 50 percent BOD removal to 97.5 percent in the following steps: 50, 60, 70, 80, 90, 95, and 97.5 percent. It was assumed that municipal wastes would be given a minimum of 70 percent treatment in 1980 and a minimum of 80 percent treatment in 2000. In aggregating total dilution requirements and costs of municipal and industrial treatment it was assumed that in 1980 treatment levels varied in the following joint manner: 70 percent municipal with 50 percent industrial, 70 percent municipal with 60 percent industrial, 70 percent municipal with 70 percent industrial, 80 percent municipal with 80 percent industrial, 90 percent municipal with 90 percent industrial and so forth. The same method of addition was used for 2000, except for the change in minimum waste treatment for municipalities.[40]

The costs of waste treatment for each level of BOD removal were combined with the costs of storage that is required in order to assure the stipulated quality maintenance flow. Waste treatment and flow regulation are both subject to decreasing marginal physical productivity, keeping constant the quantity of waste (which is a function of population and production) and the dissolved oxygen content of surface waters. Put differently, successive increments of dissolved oxygen in the streams, whether achieved by waste treatment or flow dilution or both, are subject to diminishing marginal physical productivity. The relationship between variation in treatment levels, required flows, the costs of treatment, and the costs of storage had to be separately ascertained for each region.

---

[39] A component of loss that has not yet been mentioned is the discharge of used water into estuarine bodies or directly into the ocean. Since this occurs only along the coast and its magnitude is not known for water resource regions, no special computation was incorporated into regional totals of water loss. A side effect that was included in the analysis, however, is the fact that such discharge requires no fresh water dilution. In computing waste dilution requirements assumed rates of discharge into salt water were adopted for metropolitan areas such as New York, Los Angeles, etc., and for discharge into the Great Lakes by cities to whom these bodies of water were accessible.

[40] When time permits, the data will be further analyzed by combining all different possible combinations of municipal and industrial waste treatment. Each variation in combination will yield a different waste dilution flow and treatment cost. All computations for this report are based upon the requirement that oxygen content be 4 parts per million (i.e., 4 milligrams per liter). Just as we can study the effects of different percentage combinations of municipal and industrial waste treatment, we can study the effects of higher or lower dissolved oxygen contents. Each change in dissolved oxygen content is associated with a change in storage requirements up to the maximum theoretical regulatory capacity within each region.

Given the costs for each level of waste treatment within a region, the next step in the analysis was to ascertain the costs of varying minimum flows. On the basis of the data previously described on costs of storage, it was possible to construct a schedule for each region that showed by how much total costs of storage would rise with given increases in minimum flow. So long as flow requirements were within the capacity of the region (i.e., where minimum required flows were equal to or less than maximum attainable sustained flow), it was possible to compare the costs of different combinations of treatment and storage that would provide water with the stipulated quality characteristics.[41] All costs were converted to annual costs including amortization. Since the relationship between quantity of storage and unit costs of storage were initially estimated as capital costs, the latter were converted to annual costs by assuming that annual costs were equal to 4½ percent of capital costs.[42]

As the tables in part III reveal, in some basins the combination of treatment and storage that would cost the least total amount coincided with the level of treatment that required the lowest waste dilution flow; in some basins this was not the case. Furthermore, in some basins both the minimum cost combination and the minimum dilution requirement coincide with the maximum level of treatment (97½ percent). In other regions minimum dilution requirements coincided with lower levels of treatment.

From the data on storage costs and flow/storage relationships it was also possible to measure marginal costs of minimum flows: the addition to the cumulative costs of storage resulting from successive increments in minimum flow. Not only was it possible to compare marginal changes in storage cost with marginal changes in treatment cost (the comparison needed to ascertain the minimum cost combination), but in regions in which total losses from use are high (and which, therefore, significantly affect minimum flow requirements), it is possible to see how marginal storage and treatment costs would be affected by varying the pattern of use. The form in which our data were finally assembled, therefore, provided a relatively sophisticated framework within which a number of elements could be varied and judgments regarding prospective water resource problems rendered. It is possible to see what development of water resources is required for each region in order to allow all projected demands to be met or as many as can be met within the limits of the region's supply. It is possible to judge, within the horizons of 1980 and 2000, when this development is needed. On the basis of projected demands and assumed technology of water use it is possible to determine in which regions a maladjustment between water supply and demand will be most acute and in which regions a lesser order of urgency can be anticipated. It is possible to ascertain what projected uses of water will contribute most to prospective needs for regulation and storage. It is possible to ascertain to what degree the difficulty of meeting future requirements will result from inadequate treatment, inadequate storage, or inadequate average runoff. It is possible to estimate the costs of regulation and storage within each region; other water costs, such as those for local pumping, water treatment, irrigation facilities, and so forth, can be incorporated when necessary to yield an all-embracing picture.

In spite of the information yielded by the study, it should be noted that of the several questions raised by the select committee, this study makes no attempt to answer two: (1) What should be the pattern of water development? (2) What levels of cost and expenditure are justifiable for future water development?

---

[41] Where evapotranspiration losses are high, increases in reservoir capacity add less than the flows indicated by the flow-storage tables. By estimating changes in surface area associated with increases in storage capacity, the change in net yield could be computed. In Western regions the marginal cost of yield is raised substantially by the increase in reservoir losses.

[42] Corps of Engineers experience indicated that annual costs of storage varied between 4 and 5 percent of capital costs, depending on special circumstances of operation and maintenance. An interest rate of 2½ percent and a 50-year life is implicit in these computations. At current yields on long-term bonds the annual charges would be about 6½ percent of capital costs.

In order to provide an economic answer to these we should have to know what distribution of population and economic activity would minimize the total water bill of the Nation, what the variation in all other costs would be as we minimized water costs, and whether a move toward minimizing either water costs or total costs would react on total population and on the level and pattern of economic activity within the Nation as a whole. We should also have to know the circumstances under which a plan of resource use that minimized neither water costs nor total resource costs yielded benefits that made such a plan attractive, upon whom the incidence of higher costs induced by such a plan rested, and what other goods and services or quantities of leisure would have to be sacrificed. Given all this information, it would still be a matter of judgment as to the wisdom or folly of the choices that were made; but without such information the judgments would be blind guesses.

Crude answers can be supplied, however, without the vast body of knowledge demanded by uncompromising scientific rectitude. Much light can be thrown on the relative merits of various water resource programs by developing hypothetical models that not only incorporate the levels of waste treatment and minimum flows as variables but also show the effects of transferring economic activity from one region to another. We might see, for example, that once a certain density of population and activity is reached in each region, the incremental costs of water supply are substantially the same in all regions. Our anticipation of the geographic pattern which economic growth might assume would be quite different if this were the case than if it were strikingly clear that wide variations in the marginal cost of water would not only be encountered at present among the different regions, but that this condition would also persist for some time.

Limitations and qualifications

Anyone who has studied water as an economic resource will recognize the limitations of data and the need for simplification that are inherent in this report and will qualify the conclusions accordingly. It is the purpose of this section to summarize the major limitations and qualifications to be attached to the findings.

Every step of the study is marked by a need for recognizing a margin of error, in most cases of undetermined direction as well as dimension. Our uncertainties begin with projections of population, gross national product, output of major water-using industries, and regional distribution of production and consumption. A projection is only an extension of known elements now at work or anticipated and perforce excludes all new elements of which we are still ignorant. But this is a familiar limitation generally applicable to all plans for the future and warrants no special note of caution. More important is the fact that many of our measures of behavior in the present are subject to errors of observation and aggregation. It is to these that we now turn.

Measures of water use, whether withdrawals, losses, onsite requirements, or flow requirements, contain an unknown margin of error originating in a variety of ways. Manufacturing, mining, and steam-electric power withdrawal and discharge statistics are based on questionnaire responses rather than accurate meter measurements. Municipal pumpage is usually measured, but is not adjusted for leakage. No accurate measures of municipal sewage discharge are available because of the uncertainty introduced by line leakage, line infiltration, and the mixing of storm sewer and sanitary sewer discharge. Data on irrigation and onsite losses involve specific assumptions regarding infiltration of water into the ground as well as evapotranspiration losses from reservoirs, main conveyance channels, on-farm distribution channels, and field losses. For the most part experimental data have been limited to comparatively small areas, and some problems of translation to larger regions were encountered.

The way in which new techniques of water use may affect withdrawals and losses is another element of uncertainty. While we may assume that improved technology of water use will reduce intake or gross use of water per unit of product, we cannot assume that net loss will correspondingly fall. Furthermore, the rate at which advanced techniques already known will be adopted on a wide enough scale to affect measures of water use can only be guessed. We have a basis in past history for estimating the rate of innovation, but recognized urgency, higher costs of water, or other causes contributing to concerted efforts may introduce a new trend.

Estimates of waste dilution flows, region by region, had never been made prior to the research effort instituted by the select committee. We do not know to what extent the use of regionwide measures of flow, temperature, and velocity of streamflow and an arbitrarily assumed pattern of waste outfall led to overestimation or underestimation of dilution requirements. Furthermore, we do not know to what extent a wholly new technology of waste disposal, were this to be achieved in response to a well-organized research program, would modify required dilution flows. Equally uncertain are the waste treatment problems likely to be induced by continued and cumulative effects of pesticides, herbicides, and detergents, to say nothing of processes and waste products of which we are still ignorant.

"Required flows" have been defined as the sum of losses plus flows required for waste dilution in order to maintain water quality. "Dilution" is, perhaps, poor nomenclature since the flow so stipulated is to be interpreted as total streamflow including the volume of waste that has been discharged. The required flow for quality maintenance was calculated on the assumption that within each region the volume of waste discharge was distributed in proportion to the volume of flow. If, in fact, a different pattern of waste discharge prevails, required flows are understated.

A number of uncertainties are attached to our measures of supply, beyond the normal range of probability that is inherent in all hydrologic estimates for the future.

Most important, perhaps, is the fact that supply is defined as surface runoff, without any adjustment for the possibility of mining ground water. Related to this is the failure to consider the possibility of substituting underground storage for surface storage. The net effect of these omissions is to overstate the imminence of water shortage and the costs of regulatory storage. The way in which the costs of increments of sustained flow were estimated most likely involves an error in the opposite direction. In the absence of a schedule of potential reservoir sites determined by actual study of each region, it was assumed that the aggregate of additional storage to be installed between now and the year 2000 would approximately reproduce the percentage distribution of storage capacity by size class that existed in 1954. To the extent that the best sites have already been used, it is likely that added storage capacity will consist of a proportionately greater fraction of small capacity reservoirs than are reflected in the 1954 distribution. Three other causes contributing to an understatement of total storage costs are (1) failure to consider storage for such special purposes as flood control, silt deposition, fish and wildlife habitat, navigation, and hydroelectric power, when any or all of these uses require storage in excess of the amounts stipulated for maintaining water quality; (2) underestimation of total storage required for flow regulation resulting from a conversion of concentrated seasonal requirements into an average daily need; (3) intraregional disparities between points of use and origin of supplies.

A final possible source of underestimation of storage costs might arise in the implicit relationship between construction costs and costs of land and relocation. Our cost curves implicitly assume that the passage of time per se has no effect on costs. To the extent that land costs and relocation costs will rise as a result of increasing density of population and intensity of land use without a corresponding fall in construction costs resulting from advances in technology, total costs of storage will have been understated.

The general conclusions of our study depend upon the emphasis given to storage as a means of augmenting low flow. If new techniques of controlling runoff are developed such as by weather modification, control of snowmelt, or changes in land cover, the role played by surface storage and the implicit relationship between runoff and ground water may be changed. The present state of knowledge regarding these and other modifications of supply such as utilization of sea water and its conveyance over greater distances did not lend itself to systematic analysis. One should not conclude, however, that these potential developments are of no consequence, but only that we know very little of their potential importance.

Several other major omissions in our study should also be noted. First of all, no attention was given to the possibility of augmenting supplies by interbasin transfers. Such transfers, except for comparatively modest intrastate diversions, would require negotiation of interstate compacts and for purposes of the computations it was assumed that such transfers would not take place. Major technological developments could, of course, prove such an assumption to be in error. Another omission was the failure to incorporate elasticity of demand for water as an explicit variable determining the rate of water loss or the demand for waste dilution. Very little information on the shape of the demand curve for water is available; what little there is indicates a comparatively high degree of inelasticity. If the facts should turn out to be otherwise, an adjustment to rising water costs could take one or more of several paths: (1) Intensified efforts at improving the technology of water supply and use; (2) substitution of dry processes for wet processes; (3) substitution of non-water-using goods and services for water-using goods and services; (4) geographic redistribution of activities designed to minimize the costs of water to the user or to the economy as a whole, or to both.

A final omission concerns matters of law and administrative procedure. As soon as important decisions regarding the allocation of water among competing uses are required, the institutional machinery whereby these decisions are made becomes a matter of corresponding importance. A variant of the general problem of allocation of use are the decisions relating minimum flows to levels of waste treatment. We have, however, carefully refrained from crossing the threshold of law and administration because the problems are complex, the literature extensive, and our findings designed to answer different questions.

Lest this recital lead to the conclusion that our results are of no consequence, a few words in support of the findings are in order. First of all, the way in which the data are organized will make it easier for researchers to proceed with criticism, revision, or verification of the results. Second, if the framework of analysis survives the test of scientific criticism, a continuing program of research will make it comparatively easy to modify plans and programs well ahead of any emergency. Third, the findings are the best that are available, appear to be reasonable in terms of what we have vaguely known or suspected, and indicate several steps that can be taken even if we assume the possibility of a significant range of error in the statistics and quantitative results.

PART III. THE RESULTS

Introduction

Because this report is a summary statement rather than a detailed description of findings, the facts presented herein have been reduced to a minimum. The order of discussion is as follows:

(*a*) Basic projections of population and production.

(*b*) Projected changes in uses of water: Withdrawals, losses, and flows.

(*c*) Comparison between projected uses and supply available from runoff.

(*d*) Measures of supply, elements of costs, and the costs of several alternative water resource programs.

(*e*) Some indications of the "burden" of alternative water resource programs relative to both prospective changes in gross national product and currently experienced expenditures on water resources.

(*f*) Some examples of the impact of a water resource program on selected regions.

(*g*) The significance of taking a calculated risk on storage capacity.

Projections of population and production

Basic to all projected changes in demand for water were estimates of population, gross national product, and indexes of industrial production for 1980 and 2000. Tables 8 and 9 show estimated total population and urban population, respectively, for 22 water resource regions and the United States as a whole.[1] Although population estimates are given for three levels—high, low, and medium—this report will concentrate on the implications of the medium figures.[2]

---

[1] See Committee Print No. 5, op. cit., for a detailed discussion of population estimates and tables showing revised projections. The estimates in tables 1 and 2 of this report were preliminary figures prepared quickly at the time the study got underway without benefit of projections by States later made available by the Bureau of the Census, and were based upon an extrapolation of experience between 1940 and 1950, with a dampening effect introduced. Since the preliminary projections were the only ones which Federal agencies had at the time their studies were made, they have been retained for purpose of this report. In some basins the newer figures would require modification of water demand estimates where demands were dependent on regional rather than national population projections. The effect of shifting to a revised population base would not materially alter water supply-demand relationships.

[2] The preliminary manuscript of a current Resources for the Future study, "Resources in the American Future," includes detailed discussion of the bases of estimates of population, gross national product, and industrial production.

TABLE 8.—*Total population, continental United States, water resource regions, 1950, 1960, 1980, and 2000*[1]

[Millions]

	1950	1960	1980			2000		
			Low	Medium	High	Low	Medium	High
New England	9.1	9.6	10.9	11.8	13.5	11.5	14.2	18.5
Delaware and Hudson	20.5	23.4	27.9	30.3	34.5	31.2	38.5	50.4
Chesapeake Bay	8.5	10.6	13.5	14.6	16.7	16.5	20.4	26.7
Southeast	16.4	19.7	24.4	26.5	30.1	29.2	36.1	47.2
Eastern Great Lakes	10.4	12.6	16.2	17.6	20.0	19.9	24.5	32.1
Western Great Lakes	11.3	13.7	17.5	19.0	21.7	21.1	26.0	34.0
Ohio	16.2	19.5	24.0	26.0	29.6	27.7	34.1	44.7
Cumberland	1.2	1.3	1.4	1.5	1.7	1.4	1.7	2.3
Tennessee	2.8	3.1	3.3	3.6	4.1	3.4	4.1	5.4
Upper Mississippi	10.6	12.3	14.7	15.9	18.1	16.2	20.0	26.2
Lower Mississippi	4.1	4.5	4.7	5.1	5.8	4.7	5.9	7.7
Upper Missouri	5.3	5.9	6.5	7.0	8.0	6.7	8.2	10.8
Lower Missouri	2.2	2.2	2.4	2.6	2.9	2.2	2.8	3.6
Upper Arkansas-White-Red	3.3	3.7	4.2	4.6	5.2	4.5	5.5	7.2
Lower Arkansas-White-Red	3.7	3.7	3.5	3.8	4.3	3.0	3.7	4.8
Western Gulf	6.9	8.6	11.6	12.6	14.3	[illegible]	17.6	23.1
Upper Rio Grande and Pecos	1.0	1.2	1.6	1.8	2.0	2.2	2.8	3.6
Colorado	1.2	1.7	2.6	2.9	3.2	3.6	4.4	5.8
Great Basin	.8	1.1	1.7	1.8	2.1	2.4	2.9	3.8
Pacific Northwest	4.6	5.9	7.6	8.3	9.4	10.0	12.4	16.2
Central Pacific	5.0	7.2	11.9	12.9	14.7	17.5	21.6	28.2
South Pacific	5.6	8.1	12.6	13.7	15.6	17.6	21.7	28.4
United States	150.7	179.5	224.9	243.8	277.6	266.7	329.3	430.8

[1] Projections of regional populations exclude nonresident population. Sum of individual regions do not exactly add to the total because of rounding. Absolute amounts contained herein were obtained by applying projected regional percents of total population.

Sources: 1950, from Bureau of Census county populations; 1960, 1980, and 2000 estimated on basis of Resources for the Future national projections. Mr. Constantine Mastrantonis of Resources for the Future was responsible for making regional projections.

TABLE 9.—*Urban population, water resource regions, 1950, 1960, 1980, and 2000* [1]

[Millions]

	1950	1960	1980			2000		
			Low [2]	Medium	High [2]	Low [2]	Medium	High [2]
New England	7.0	7.3	7.7	9.0	10.9	7.2	10.9	15.8
Delaware and Hudson	16.5	20.1	25.5	28.2	32.6	29.5	37.2	49.3
Chesapeake Bay	5.2	7.3	10.0	11.6	13.9	12.8	17.6	24.4
Southeast	7.0	10.1	13.5	16.9	21.2	16.6	26.4	39.4
Eastern Great Lakes	8.1	10.1	13.0	15.0	17.4	15.8	21.4	29.6
Western Great Lakes	7.9	10.0	12.8	14.9	17.9	15.3	21.6	30.4
Ohio	10.2	12.9	15.8	18.8	22.9	17.5	26.3	38.4
Cumberland	.5	.6	.7	.9	1.1	.6	1.1	1.8
Tennessee	1.2	1.6	1.7	2.2	2.8	1.8	2.9	4.4
Upper Mississippi	6.0	7.5	9.1	11.0	13.5	9.7	15.0	22.2
Lower Mississippi	1.7	2.2	2.5	3.2	4.0	2.6	4.3	6.4
Upper Missouri	2.4	3.0	3.5	4.4	5.5	3.5	5.8	8.8
Lower Missouri	1.3	1.3	1.5	1.9	2.2	1.4	2.2	3.1
Upper Arkansas-White-Red	1.8	2.3	3.0	3.5	4.2	3.4	4.6	6.5
Lower Arkansas-White-Red	1.7	2.1	2.2	2.7	3.3	2.0	3.0	4.2
Western Gulf	4.4	6.5	10.1	11.3	13.1	13.3	16.8	22.5
Upper Rio Grande and Pecos	.5	.8	1.2	1.4	1.7	1.8	2.5	3.4
Colorado	.7	1.2	2.0	2.4	2.8	3.0	4.0	5.4
Great Basin	.5	.8	1.4	1.5	1.8	2.0	2.6	3.6
Pacific Northwest	2.7	3.8	5.2	6.2	7.4	7.0	10.1	14.3
Central Pacific	4.0	6.3	11.2	12.3	14.1	17.0	21.2	27.9
South Pacific	5.1	7.8	12.5	13.6	15.5	17.6	21.7	28.4
United States [3]	96.5	125.5	166.1	192.6	229.8	201.4	279.4	390.2

[1] Figures exclude Armed Forces overseas as well as Alaska and Hawaii. Total for U.S. rural is built up from individual regions which in turn have been projected on the basis of 1940-50 change in the percent rural population was of total population within equivalent water resource combinations of States. Urban populations were then obtained by subtracting rural populations from total.

[2] High regional urban population is obtained by subtracting low rural from high total; conversely, low regional urban population is obtained by subtracting high rural from low total.

[3] Totals derived by adding individual items. Because of larger latitude for variation, sum of U.S. minimum totals for rural and urban populations will be less than national minimum and sum of U.S. maximums will be greater than the national maximum.

Sources: See table 8.

A number of generalizations are quickly revealed by the projections for separate water resource regions.

(*a*) Regions in which population is projected to grow in the neighborhood of 50 to 80 percent during the period 1960–2000 are New England, Delaware and Hudson, Ohio, Upper Mississippi, and the Upper Arkansas-White-Red.

(*b*) Regions in which population is projected to grow by less than 50 percent are Cumberland, Tennessee, Lower Mississippi, Upper Missouri, Lower Missouri, and Lower Arkansas-White-Red.

(*c*) Regions in which growth is projected in the neighborhood of 80 percent or more include Chesapeake Bay, Eastern Great Lakes, Southeast, Western Great Lakes, Western Gulf, Rio Grande-Pecos, Colorado, Great Basin, Pacific Northwest, Central Pacific, and South Pacific.

What strikes one immediately is that of the 11 regions falling into the high growth class, 7 are in the West, of which 4—Rio Grande-Pecos, Colorado, Great Basin, and South Pacific—have suffered water shortage for many years, and another, Western Gulf, is characterized by a deficiency of runoff in several of its western parts.

Urban populations given in table 9 were used to estimate municipal water demand and waste load As inspection of tables 8 and 9 reveals, urban population is expected to grow faster than total population. Regions in which the projected total propulation growth rate is moderate show substantial increases in urban population. The lower Arkansas-White-Red, for instance, is projected to have a constant total population (at medium projections) over the period 1960–2000, whereas urban population is projected to grow by 50 percent.[3]

In some regions a high rate of urban growth is tempered by the fact that the 1960 absolute level is comparatively low—800,000 in the Great Basin and a similar number in the Rio Grande-Pecos. In other regions, however, a high growth rate starts with a respectable number for 1960—

---

[3] The preliminary projection of urban population was based on the assumption that rural population in 2000 would be 50 million for the medium projection. Later study indicated that a projected rural population of about 70 to 75 million seemed more reasonable as a result of the rapid growth in rural nonfarm population. These differences would have little effect on domestic demand for water. If rural nonfarm residents are not served by central sewage collection and treatment facilities, the effect of the difference in projections would be to overstate by about 10 percent municipal dilution requirements.

7,800,000 in South Pacific, for example. This is projected to almost 22 million by the year 2000.[4]

If water use were to grow in proportion to total population, we should expect to see a 36-percent growth between 1960 and 1980 and something less than a 35-percent growth again between 1980 and 2000. The results of our study, however, indicate that prospective changes in urban population more closely parallel prospective changes in water use than do changes in total population. It can be inferred, therefore, that urban activities and activities stemming from urban residence will have been the major elements in changing the pattern of water use between now and the year 2000.

As a supplement to changes in population, it was necessary to have some knowledge regarding expected changes in gross output and the output of water-using goods. Table 10 shows the projected values for gross national product, the overall index and six components of the index of industrial production, and estimated electric power production by utility and industrial power plants. These values were the basis for the regional distribution of major water-using manufacturing industries or, where Federal agencies chose to use another method or level of projecting national output, the basis of the spread between high and low estimates.

Anticipated growth in gross national product is substantially greater than growth in urban population. A doubling of gross national product between 1960 and 1980 is indicated by the medium projection, with a doubling again between 1980 and 2000. The low series indicates a tripling of gross national product over the period 1960–2000, whereas the high series indicates a sextupling.

The actual path taken by economic growth cannot, of course, be predicted. The range of projections, of population as well as output, facilitates planning even if the realized path of growth is quite different from the smoothly progressing series of points that a long-range projection may imply. For example, the high urban population projection for 1980 is higher than the low projection for 2000. If we were now to plan for 1980 high, we would, in 1980, be 20 some years ahead of schedule (assuming we kept to our original plan) if the actual rate of growth was moving along the low path. In 1980 we might see that the high that had been projected in 1960 for 2000 was now unattainable. We could therefore revise the high-low-medium spectrum for 2000 on the basis of knowledge gained during the period 1960–80. The main significance of the projection is not its use as a predictive device but its use as a stimulant to systematic thought and planning. Once the relevant variables have been selected and measured, interrelations established, and implications made explicit, an observed deviation between what is realized and what had been assumed in the projection will usually require little more than a speedup or stretchout of a program already adopted.

Something of the problem anticipated for the years 1980 and 2000 is to be seen in the projections for food, pulp and paper, chemicals and petroleum refining. These are the major industrial water pollutants. At the medium levels, food manufacturing is projected to somewhat more than twice the 1960 level by 2000. Pulp and paper output, however, is estimated to grow by six times between 1960 and 2000, and chemicals to grow by

---

[4] Results yielded for the South Pacific by other techniques that were studied in the process of revising the projections were twice as high by the year 2000. Almost anything might happen here.

TABLE 10.—*Selected economic measures, 1954, 1960, 1980, and 2000*

	1954	1960	1980			2000		
			Low	Medium	High	Low	Medium	High
Gross national product [1]	426	518.7	960	1,060	1,260	1,680	2,200	3,290
FRB index of industrial production (1947–49=100)	125	161.0	303	353	435	562	796	1,150
Food	106	117.0	165	188	229	213	296	441
Pulp and paper	132	186.0	388	482	663	788	1,190	2,170
Pig iron and steel	108	155.0	187	303	497	283	613	1,410
Aluminum (primary)	244	341.0	738	1,920	4,620	1,420	5,150	18,600
Chemicals	148	215.0	559	673	839	1,330	1,850	2,790
Petroleum refining	133	161.0	258	308	364	388	584	869
Electric power generation (billion kilowatt-hours)	547	852.0	(2)	2,459	(2)	(2)	5,421	(2)

[1] In billions of 1960 dollars.
[2] Not yet available.

Source: Preliminary manuscript, "Resources in the American Future," Resources for the Future, Inc.

almost nine times. Even if the low series is adopted, the problem of industrial pollution looms large. Food processing would almost double, pulp and paper output would grow by four times, chemicals would grow by more than six times, and petroleum refining would more than double.

Because regional growth of population is not uniform, market oriented industries will grow more rapidly in regions of rapid population growth than elsewhere. To some degree the regional demand for water will be subject to a multiplier effect: (1) Growth in domestic requirements, (2) growth in market-oriented industrial requirements, (3) growth in waste-dilution requirements reflecting the sum of (1) and (2). It is largely for this reason that projected water use appears to grow with unlikely rapidity in certain parts of the country. The speed at which growth of use is projected is further enhanced when two comparatively new forces are considered: (1) Extension of irrigation into the eastern half of the country plus further penetration in the West made possible by newer techniques of construction and distribution; (2) a truly phenomenal increase in the demand for water-based outdoor recreational resources. Both of these demands for water are also partly market oriented. And what is of special significance is the fact that irrigation and certain forms of wildlife habitat—swamps and wetlands—are the two major depleting uses of water.

Table 11 shows the indexes of production used by Federal agencies in lieu of, or as supplements to, projections supplied by "Resources for the Future."

Table 11.—*Indexes of production used to derive estimates of water use*

MANUFACTURING INDUSTRIES

	1954	1980		2000	
		BDSA	RFF [1]	BDSA	RFF [1]
Food	100	153	177	190	279
Pulp and paper	100	280	365	586	902
Chemicals	100	338	455	811	1,250
Petroleum refining	130	(2)	240	(2)	304
Major primary metals	100	277	289	390	593

Table 11.—*Indexes of production used to derive estimates of water use*—Continued

UTILITY POWER PRODUCTION

	1954	1980	2000
Hydroelectric	100	261	336
Steam	100	477	1,075

AGRICULTURE

	1954	1980			2000		
		Low	Medium	High	Low	Medium	High
Domestic output	100	158	169	190	188	227	291

MINERALS PRODUCTION (BASED ON WATER INTAKE)

	1954	1980	2000
Metals	100	109	137
Nonmetals	100	138	219
Petroleum products	100	165	165
Natural gas, liquid refineries	100	153	153
Bituminous coal	100	190	190
Anthracite	100	59	103
Total	100	210	266

[1] "Resources for the Future" medium projection included for comparative purposes.

[2] Petroleum refining under jurisdiction of Bureau of Mines.

Note.—BDSA indexes of industrial production computed as a single preferred series. They conformed to RFF lows (except for aluminum) and were incorporated into total of low projections. USDA estimates of agricultural production independently estimated on basis of RFF projections of population and GNP. Bureau of Mines estimates of minerals production conformed approximately to RFF medium projections and were used as such. FPC estimates for utility power production conformed approximately to RFF medium projections and were used as such.

Projected changes in the demand for water: Withdrawals

Tables 12 to 14, inclusive, summarize the withdrawal demands for water. "Agriculture" includes water for farm animals as well as the total of rural farm and nonfarm domestic use. Mining excludes mine water. Manufacturing includes food, pulp, and paper, chemicals, petroleum refining and coal products, and primary metals; plus all other manufacturing categories; plus an estimate for small water users not covered by the 1954 Census of Manufactures. Steam-electric power is that for public utilities only; industrial power is included within manufacturing. Municipal water use includes residential, commercial, public, and whatever industrial uses are supplied from municipal systems.

In the last column of table 12 a reference figure is shown; namely, the minimum flows under present regulation, before depletion.

TABLE 12.—*Withdrawal uses: Total withdrawals, 1954*

[In million gallons per day]

	Agriculture	Mining	Manufacturing	Steam-electric	Municipal	Total	Flow now equaled or exceeded 95 percent of time
New England	101	17	1,624	3,571	1,022	6,335	6,300
Delaware and Hudson	255	68	3,071	8,927	2,360	14,681	3,200
Chesapeake Bay	172	66	1,551	4,464	812	7,065	5,600
Southeast	1,726	170	2,099	6,249	998	11,242	21,000
Eastern Great Lakes	125	42	4,036	5,356	1,675	11,234	2,300
Western Great Lakes	205	100	4,329	6,249	2,052	12,935	8,400
Ohio	334	166	5,789	14,284	1,439	22,012	7,400
Cumberland	32	2	49	----------	75	158	1,500
Tennessee	100	46	641	2,678	191	3,656	9,000
Upper Mississippi	382	76	1,518	5,356	1,075	8,407	7,800
Lower Mississippi	1,438	102	912	1,786	238	4,476	2,100
Upper Missouri	25,369	71	307	1,786	372	27,905	1,800
Lower Missouri	125	3	118	893	180	1,319	410
Upper Arkansas-White-Red	6,181	41	148	1,786	251	8,407	640
Lower Arkansas-White-Red	1,481	42	342	1,786	225	3,876	1,000
Western Gulf	14,310	155	3,090	4,464	667	22,686	920
Upper Rio Grande and Pecos	8,783	38	47	----------	84	8,952	245
Colorado	26,403	58	44	----------	187	26,692	905
Great Basin	12,272	71	96	----------	172	12,611	840
Pacific Northwest	22,756	40	1,156	----------	762	24,714	9,700
Central Pacific	46,973	46	526	1,786	733	50,064	1,300
South Pacific	6,601	38	408	2,678	1,104	10,829	116
United States	176,124	1,458	31,901	74,099	16,674	300,256	90,000

The relative importance of different withdrawal uses varies in 1954 from region to region. Several generalizations can be made:

(1) Domestic use is a comparatively small part of total use, since all municipal withdrawals (which include commercial and some industrial customers) amount only to 5 percent of the total of all withdrawals. In the East, the percentage tends to be substantially higher—e.g. about 16 percent in New England; in the West, the percentage is considerably lower—e.g. less than 1 percent for Rio Grande-Pecos and Colorado.

(2) Of nonagricultural uses, cooling water for steam-electric utilities is the greatest. If we were to add to steam-electric requirements, the cooling water requirements of manufacturing the total for 1954 would be about 95,000 million gallons per day (about two-thirds of total manufacturing uses plus all of steam-electric power uses; water used for boiler feed by steam-electric utilities is included in the total of their requirements but is a comparatively small amount), or 32 percent of total withdrawals.

(3) The largest category of use is agriculture; 1954 figures probably overstate agricultural withdrawals by some substantial amount since they were computed on a basis comparable to the estimate for 1980 and 2000, which assumed applying to the plant all the water it could beneficially use.[5] Actual applications fell short of this in most regions in 1954.

(4) A retabulation of withdrawals in accordance with a modified scheme of classification yields the following:

1954 withdrawals	Million gallons per day	Percent
Agriculture	176,000	59
Cooling water, manufacturing, and utilities	95,000	32
Mining and manufacturing process water	13,000	4
Municipal	17,000	6
Total withdrawals	300,000	100

(5) Total withdrawals fell short of minimum flows in Southeast, Cumberland, and Tennessee regions. Total withdrawals were less than twice minimum flows in New England, Chesapeake Bay, Western Great Lakes, and Upper Mississippi. In the first three regions water was "used" on the average only once; in the four latter regions, between once and twice.[6] In the remaining regions, a substantial amount of reuse is indi-

---

[5] See MacKichan, op. cit., for 1955 estimate of 110,000 million gallons per day for irrigation. Figures in tables 12 to 14, inclusive, include stock watering and rural domestic use in addition to irrigation uses, and besides are for 1954, which was generally speaking, a drier year than 1955.

[6] If ground water is used to a substantial degree, the computed multiple of reuse might be an incorrect measure of actual reuse. Ground water storage can serve the same function in regulating supply as surface water storage. If, however, there were extensive contributions from ground water reservoirs during periods of low surface flow, it is likely that, except for water being used for irrigation, this water would appear as surface runoff after use (net of losses).

cated. In the East the impact of reuse is modified to the extent that such a large proportion of total withdrawals is represented by cooling water. In the West, the impact of reuse is cushioned by the fact that the major withdrawal is for irrigation, and it is the return flow from the fields that is used again downstream—usually more mineralized, however, than in its upstream state.

Tables 13 and 14 indicate estimated withdrawals for 1980 and 2000, medium projections. If we compare national totals we see that withdrawals between 1954 and 1980 will rise by 86

TABLE 13.—*Withdrawal uses: Total withdrawals, 1980*

[In million gallons per day]

	Agriculture	Mining	Manufacturing	Steam-electric	Municipal	Total
New England	294	8	4,616	11,606	1,477	18,001
Delaware and Hudson	439	65	8,285	23,211	3,753	35,753
Chesapeake Bay	410	65	5,471	13,391	1,440	20,777
Southeast	3,328	81	8,115	25,889	1,832	39,245
Eastern Great Lakes	320	150	12,208	16,962	2,763	32,403
Western Great Lakes	571	92	11,556	22,318	3,360	37,897
Ohio	858	304	15,433	48,208	2,374	67,177
Cumberland	70	4	296	----------	119	489
Tennessee	196	28	2,334	8,927	311	11,796
Upper Mississippi	921	222	3,523	16,069	1,759	22,494
Lower Mississippi	2,110	154	2,441	3,571	387	8,663
Upper Missouri	25,361	87	688	7,142	618	33,896
Lower Missouri	248	9	296	1,786	279	2,618
Upper Arkansas-White-Red	5,841	55	422	5,356	419	12,093
Lower Arkansas-White-Red	2,099	50	1,041	3,571	341	7,102
Western Gulf	13,207	230	13,099	15,177	1,275	42,988
Upper Rio Grande and Pecos	8,168	46	129	1,786	159	10,288
Colorado	22,770	750	137	3,571	397	27,625
Great Basin	10,645	43	274	1,786	345	13,093
Pacific Northwest	20,583	47	8,452	4,464	1,402	34,948
Central Pacific [1]	43,528	120	1,567	13,391	1,603	60,209
South Pacific	5,199	62	1,173	10,713	2,175	19,322
United States	167,166	2,672	101,556	258,895	28,588	558,877

[1] See footnote 1 on table 14. The same general comment would apply to 1980, although the Bureau of Reclamation did not make an estimate specifically for 1980.

TABLE 14.—*Withdrawal uses: total withdrawals, 2000*

[In million gallons per day]

	Agriculture [1]	Mining	Manufacturing	Steam-electric	Municipal	Total	Flow now equaled or exceeded 50 percent of time
New England	491	13	10,030	18,748	2,022	30,304	39,000
Delaware and Hudson	571	94	17,014	35,709	5,301	58,689	19,000
Chesapeake Bay	1,533	104	11,688	20,533	2,193	36,051	32,000
Southeast	9,662	124	19,534	41,066	2,818	73,204	126,000
Eastern Great Lakes	839	271	25,392	27,675	4,052	58,229	19,000
Western Great Lakes	1,515	141	23,504	35,709	4,593	65,462	32,000
Ohio	2,428	419	29,386	74,990	3,471	110,694	46,000
Cumberland	152	5	677	893	163	1,890	7,800
Tennessee	423	39	5,633	17,855	441	24,391	28,000
Upper Mississippi	5,359	310	6,767	24,997	2,535	39,968	41,000
Lower Mississippi	3,478	162	6,405	5,356	546	15,947	21,000
Upper Missouri	32,462	79	2,211	11,606	867	47,225	14,000
Lower Missouri	1,520	12	904	3,571	368	6,375	5,800
Upper Arkansas-White-Red	6,565	56	1,274	8,035	581	16,511	6,800
Lower Arkansas-White-Red	3,185	55	2,378	5,356	432	11,406	20,000
Western Gulf	13,960	260	38,709	24,104	1,907	78,940	14,000
Upper Rio Grande and Pecos	7,011	55	745	2,678	270	10,759	1,870
Colorado	19,965	734	671	8,035	647	30,052	7,100
Great Basin	9,229	40	751	2,678	579	13,277	6,000
Pacific Northwest	21,812	63	19,315	16,962	2,262	60,414	76,000
Central Pacific	37,512	245	3,671	24,997	2,715	69,140	18,700
South Pacific	4,558	110	2,548	17,855	3,420	28,491	840
United States	184,230	3,391	229,207	429,408	42,183	888,419	560,000

[1] Estimates of prospective changes in irrigated acreage and irrigation water requirements are based on projections of USDA. Estimates made by Bureau of Reclamation were received too late for incorporation in this preliminary report but will serve as a basis of alternative models of water use for final report. A major difference between 2 estimates is in additional irrigated acreage projected for 2000. USDA estimated the increase to be about 1,000,000 acres for the medium projection and about 3,500,000 acres for the high projection. The Bureau of Reclamation estimated the increase to be about 6,000,000 acres. Thus, the Bureau of Reclamation projection, if realized, will result in a much tighter water situation than is projected on the basis of USDA estimates.

percent. Between 1954 and 2000 the increase will be 196 percent.[7] A reference figure of flow equalled or exceeded 50 percent of the time, prior to depletion and under current regulation is included in table 14.

The shifting patterns of water use projected for the future are indicated by several rearrangements of the data. First of all, we see that the relative importance of irrigation withdrawals declines, and, along with that, there is a change in the regional distribution of withdrawal use. In 1954, the nine western regions accounted for 64 percent of all withdrawals; by 1980 this figure is projected to fall to 46 percent and by 2000 to 40 percent.

The pattern of use by 2000 would look approximately as follows (assuming the same proportion of manufacturing water is used for cooling as in 1954):

Withdrawals: 2000	Million gallons per day	Percent
Agriculture	184,000	21
Cooling water, manufacturing and utilities	576,000	65
Mining and manufacturing process	85,000	10
Municipal	42,000	5
Total	888,000	100

On a national basis the pattern of use for the year 2000 indicates several significant impending changes:

(*a*) The growth in irrigation accounts for a very small part of the growth in total use, although, as we shall see below, a greater percent of growth in depletions.

(*b*) Without substantial changes in the way in which cooling water is used, our streams face a sixfold increase in cooling demands. (The total number of B.t.u.'s returned to the streams can probably be computed; from this the potential rise in stream temperature might be inferred.)

(*c*) Mining and manufacturing process water and municipal water requirements are estimated to rise to an amount four times 1954 use. With no change in the percent of organic waste removed by treatment, this implies a fourfold increase of 1954 levels in the volume of organic waste discharged into streams. If it is assumed that treatment were raised to twice its present level (roughly, say, from 40 to 80 percent), the waste load would still rise by two times. The increase in pollution by poisons, chlorides, chloroform extractables, and other accumulative substances cannot be estimated, since not enough is known of their present origin, quantity, and effects on water quality.

(*d*) The combined effects of prospective heat and waste discharge constitutes a significantly new dimension in water use and one that has not yet been fully explored.

(*e*) By comparing total withdrawals projected for 2000 with streamflow now available 50 percent of the time, it can be seen that for the country as a whole use of water will be equal to 1½ times, roughly, flow if all streams were regulated to the degree that has generally been considered to be a maximum; i.e., to yield, as sustained flow, flow now available 50 percent of the time. In some regions, however, the computed reuse of water for this degree of regulation would be much higher:

Indicated multiple that withdrawals for year 2000 is of flow now available 50 percent of the time (before depletions)

Delaware and Hudson	3
Eastern Great Lakes	3
Upper Missouri	3½
Upper Arkansas-White-Red	3
Western Gulf	5½
Rio Grande-Pecos	5½
Colorado	4½
Great Basin	2
Central Pacific [1]	3½

[1] South Pacific is ignored since most water is already imported.

At present (1954) withdrawals are less than the 50 percent flow for every region except as follows:

Indicated multiple that 1954 withdrawals were of flow available 50 percent of the time (before depletions)

Upper Missouri	2
Upper Arkansas-White-Red	1¼
Western Gulf	1½
Rio Grande-Pecos	4¾
Colorado	3½
Great Basin	2
Central Pacific	2½

Regions now characterized by water shortage, discussed in greater detail below, already utilize and regulate a large fraction of runoff. Prospective changes in the relationships between withdrawals and runoff will be most sharply revealed within regions in which comparatively little regulation has been deemed necessary. The prospective multiples of use for Delaware and Hudson and Eastern Great Lakes have already been indicated.

---

[7] The phrases "will" or "will be" or others similar to these are used to avoid monotonous repetition of the phrase "is projected to be."

A comparison of 1954 with 2000 is given below for a number of regions.

	Indicated multiple withdrawals is of flow available 50 percent of the time (before depletion)	
	Withdrawals in 1954	Withdrawals in 2000
New England	1/6	1
Delaware and Hudson	3/4	3
Chesapeake Bay	1/4	1
Southeast	1/10	9/10
Eastern Great Lakes	6/10	3
Western Great Lakes	4/10	2
Ohio	1/2	2 4/10
Upper Mississippi	3/10	1
Lower Missouri	1/4	1

The import of these figures is that a considerable volume of dilution water has been naturally available for substantial parts of the year for all eastern regions to offset both heat and other forms of pollution. (Special cases such as the Mahoning River in the Ohio Basin must, of course, be recognized.) If our projections of use are realized, however, not only will conditions deteriorate drastically during periods of low flow, but even during the best 6 months of an average year we can anticipate unsatisfactory conditions to prevail unless ameliorative steps are taken.

While the relationships between available flows and withdrawals in western regions indicate much smaller increases in use than in eastern regions, the difficulties facing the West (except the Pacific Northwest) are much more serious. Western regions face the prospect of such high rates of loss that entirely new methods of water use, or at least substantial revisions in the pattern of projected use, are called for.

Projected changes in the demand for water: Losses

Evapotranspiration losses were estimated for withdrawal uses and on-site uses. A similar estimate might have been made of losses incurred to provide navigation, hydroelectric power, fish habitat, and waste dilution flows, but this was not done. It would have been difficult to identify single-purpose flows or impoundments as of 1954, as well as to establish whether, and if so by how much, the flow use caused a change in evapotranspiration within the region.

For 1980 and 2000 our computations of losses are similarly restricted to identifiable withdrawal and onsite uses, except for a final adjustment for losses from additional storage. The latter is not "assigned" to any particular use.

Estimates of losses are given in tables 15 to 22. The first three of these indicate losses from withdrawal uses. Table 18 indicates the difference between estimated actual and computed irrigation losses for 1954. As already noted, agricultural losses for 1954 were computed not as losses actually incurred but as losses that would have been experienced had as much water been used as could have been beneficially transpired by irrigated crops. This correction is primarily applicable to the nine western regions and amounts to a difference of about 29,000 million gallons per day or about 29 percent of computed irrigation loss.[8] Since computed rather than actual 1954 figures are more comparable with 1980 and 2000 requirements, they will be used in estimating the changes that are indicated by our projections.

It might also be helpful to remind the reader that onsite use in 1954—for land treatment and structures and swamps and wetlands—is assumed to be accounted for in stream-gage measurements. It would be double counting, therefore, to charge *against stream runoff* losses incurred up to now from onsite uses. By a backward extrapolation from 1980 and 2000 estimates, however, an

TABLE 15.—*Losses: Withdrawal uses, 1954*

[In million gallons per day]

	Agriculture	Mining	Manufacturing	Steam-electric power	Municipal	Total
New England	61	0.2	205	2.6	102.2	371.0
Delaware and Hudson	192	5.6	178	14.6	236.0	626.2
Chesapeake Bay	113	7.6	91	(1)	81.2	292.8
Southeast	1,445	7.2	351	4.3	99.8	1,907.3
Eastern Great Lakes	82	6.3	142	2.7	167.5	400.5
Western Great Lakes	155	9.3	216	1.9	205.2	587.4
Ohio	202	51.0	296	28.6	143.9	721.5
Cumberland	18	.4	-----	-----	7.5	25.9
Tennessee	63	6.5	44	(1)	19.1	132.6
Upper Mississippi	295	14.9	142	2.7	107.5	562.1
Lower Mississippi	1,242	9.0	38	90.6	23.8	1,403.4
Upper Missouri	13,839	7.0	25	26.8	74.4	13,972.2
Lower Missouri	105	.2	11	(1)	18.0	134.2
Upper Arkansas-White-Red	3,726	21.8	60	98.2	50.2	3,956.2
Lower Arkansas-White-Red	1,237	8.9	93	17.7	22.5	1,379.1
Western Gulf	9,192	56.8	559	101.7	133.4	10,042.9
Upper Rio Grande and Pecos	5,071	23.4	3	-----	16.8	5,114.2
Colorado	15,595	13.4	16	-----	37.4	15,661.8
Great Basin	7,285	.2	30	-----	34.4	7,349.6
Pacific Northwest	12,492	5.5	82	(1)	154.4	12,733.9
Central Pacific	27,641	4.9	123	7.4	146.6	27,922.9
South Pacific	3,894	5.2	60	11.5	220.8	4,191.5
United States	103,945	265.3	2,765	411.3	2,102.6	109,489.2

(1) Losses estimated at 0.03 percent of fresh water intake for 1980 and 2000. No losses shown for 1954.

---

[8] Actual irrigation requirements by water resource region estimated by Karl Gertel, previously cited.

Table 16.—*Losses: Withdrawal uses, 1980*

[In million gallons per day]

	Agriculture	Mining	Manufacturing	Power	Municipal	Total
New England	118	0.1	529	8.6	147.7	803.4
Delaware and Hudson	316	7.2	447	38.0	375.3	1,183.5
Chesapeake Bay	220	5.9	312	3.1	144.0	685.0
Southeast	2,397	4.8	1,433	18.0	183.2	4,036.0
Eastern Great Lakes	148	13.6	403	8.5	276.3	849.4
Western Great Lakes	319	6.9	778	6.7	336.0	1,446.6
Ohio	419	85.2	866	96.4	237.4	1,704.0
Cumberland	34	.5	3	--------	11.9	49.4
Tennessee	110	3.4	170	2.7	31.1	317.2
Upper Mississippi	613	42.2	334	8.0	175.9	1,173.1
Lower Mississippi	1,889	13.9	93	181.2	38.7	2,215.8
Upper Missouri	15,011	15.9	58	107.1	123.6	15,315.6
Lower Missouri	202	.4	27	.5	27.9	257.8
Upper Arkansas-White-Red	3,749	35.2	156	294.6	83.8	4,318.6
Lower Arkansas-White-Red	1,798	11.8	288	35.5	34.1	2,167.4
Western Gulf	8,404	88.9	1,737	345.7	255.0	10,830.6
Upper Rio Grande and Pecos	4,964	27.5	5	100.0	31.8	5,128.3
Colorado	14,396	242.1	49	285.7	79.4	15,052.2
Great Basin	6,698	.2	90	66.1	69.0	6,923.3
Pacific Northwest	12,322	6.4	408	1.3	280.4	13,018.1
Central Pacific	27,040	9.6	384	55.9	320.6	27,810.1
South Pacific	3,312	7.9	175	46.0	435.0	3,975.9
United States	104,479	629.6	8,745	1,709.6	3,698.1	119,261.3

Table 17.—*Losses: Withdrawal uses, 2000*

[In million gallons per day]

	Agriculture	Mining	Manufacturing	Power	Municipal	Total
New England	280	0.1	1,090	13.9	202.2	1,586.2
Delaware and Hudson	452	10.9	891	58.4	530.1	1,942.4
Chesapeake Bay	1,245	9.8	628	4.7	219.3	2,106.8
Southeast	8,123	6.6	3,373	28.5	281.8	11,812.9
Eastern Great Lakes	605	18.4	822	13.8	405.2	1,864.4
Western Great Lakes	1,160	10.5	2,463	10.7	459.3	4,103.5
Ohio	1,811	101.2	1,803	150.0	347.1	4,212.3
Cumberland	108	.6	5	68.7	16.3	198.6
Tennessee	320	4.7	411	5.4	44.1	785.2
Upper Mississippi	4,614	58.0	633	12.5	253.5	5,571.0
Lower Mississippi	3,097	14.5	233	271.8	54.6	3,670.9
Upper Missouri	20,474	15.4	121	174.1	173.4	20,957.9
Lower Missouri	1,418	.5	96	1.1	36.8	1,552.4
Upper Arkansas-White-Red	4,582	35.7	466	441.9	116.2	5,641.8
Lower Arkansas-White-Red	2,961	12.4	638	53.2	43.2	3,707.8
Western Gulf	9,955	89.2	4,340	549.0	381.4	15,314.6
Upper Rio Grande and Pecos	4,788	34.3	68	150.0	54.0	5,094.3
Colorado	13,182	238.8	260	642.8	129.4	14,453.0
Great Basin	6,069	.1	205	99.1	115.8	6,489.0
Pacific Northwest	13,649	8.6	918	5.1	452.4	15,033.1
Central Pacific	24,394	15.2	962	104.3	543.0	26,018.5
South Pacific	3,052	10.7	405	76.6	684.0	4,228.3
United States	126,339	696.2	20,831	2,935.6	5,543.1	156,344.9

Table 18.—*Actual versus computed irrigation losses, western regions, 1954*

[In million gallons per day]

	Actual	Computed	Difference
Upper Missouri	12,134	13,617	1,483
Upper Arkansas-White-Red	2,917	3,648	731
Western Gulf	6,690	9,100	2,410
Upper Rio Grande and Pecos	1,638	5,052	3,414
Colorado	13,213	15,570	5,771
Great Basin	5,788	7,259	1,471
Pacific Northwest	14,701	12,436	−2,265
Central Pacific	10,889	27,609	16,720
South Pacific	1,346	3,875	2,529
United States	69,317	98,166	28,849

Source: Karl Gertel, special computation of actual losses, unpublished, based on MacKichan, *op. cit.* Computed losses from table 19.

attempt was made to estimate what onsite "losses" were in 1954, and the results, along with total withdrawal losses are shown in table 20. We can interpret this table as indicating that if there had been no withdrawal uses of water, if no conserving practices in land cover and land use had been adopted, and if all swamps and wetlands deemed useful as wildlife habitat had in fact been drained and covered by ordinary dryland vegetation, surface runoff in the United States would have been 202,000 million gallons per day greater than it was. These losses represent about 20 percent of average runoff for the country as a whole. In some regions, such as the Upper Missouri, the figure is much higher. Losses estimated this way for the Upper Missouri amounted to 32,600 million gallons per day. Average undepleted runoff is 29,000 million gallons per day. Withdrawal losses of 14,000 million gallons per day are charged against runoff, but remaining losses, 18,600 million gallons per day, are incurred from natural swamps and sinkholes scattered throughout the region and from conservation practices that farmers have adopted.

Of total losses indicated in table 20, withdrawal losses account for 54 percent and onsite "uses" 46 percent. The word "uses" is put into quotation marks because all onsite use except 3,500 million gallons per day is the result of leaving Nature undisturbed, and the remaining 3,500 million gallons per day is largely a repossession by Nature of soil moisture which she had lost by improper land use, accelerated runoff and soil erosion.

Looking only at losses from withdrawal uses, we see that in 1954 (see table 15) agriculture accounted for 95 percent of the total. By comparing the figures for 1954 in table 19 with total losses in table 15 we see that western irrigation (computed figures) accounted for 94 percent of all losses assigned to agriculture, including stock watering and rural domestic use, and 89 percent of national losses for all withdrawals.

By the year 2000 the projected pattern of loss changes somewhat. Agriculture accounts for only 81 percent of total withdrawal losses and western agriculture for only 64 percent. However, the largest component of the projected increase in total loss is still agriculture, which shows a growth of 22,400 million gallons per day over computed 1954 requirements, but about 50,000 million gallons per day over actual 1954 requirements.

The next largest increase occurs in manufacturing, which rises from 2,800 million gallons per day to 20,800 million gallons per day, amounting to more than a sevenfold growth.[9] While steam-electric utilities account for a large part of withdrawals, they accounted for less than one-half of 1 percent of total withdrawal losses in 1954 and are estimated to account for only 2 percent in 2000. The increase is a function of three changes: First, the fact that steam-electric utilities are assumed to be producing a larger fraction of total energy in 2000 than in 1954 (industrial production of electric power being assumed to fall in relative importance); second, the fact that the projected increase in electric power production is greater than the projected increase in the average of all withdrawal uses; and third, the fact that electric power production is assumed to increase in the Western States at a greater rate than the national average.[10]

The increase in municipal losses is a function of growth in urban population, distribution of urban growth between eastern and western regions,[11] and projected changes in per capita intake. Municipal losses grow by 2½ times, between 1954 and 2000, but are only 3.1 percent of withdrawal losses in 1980 and 3.5 in 2000.

In a document replete with large increases in almost every significant measure, it is something of a surprise to see that total losses from withdrawal uses grow by a mere 9 percent between 1954 and 1980, and only by an additional 31 percent between 1980 and 2000. These relatively modest increases are attributable to a belief by agricultural specialists that, at medium projections, irrigation requirements in the West have already reached their peak and will, from now on, remain practically constant in quantity in spite of a rather substantial increase in irrigated acreage. The difference between the trends of water used for irrigation and the extent of irrigated acreage is based upon an expectation of increased efficiency in the use of water. These efficiency projections do not rest upon knowledge that we do not yet possess, but upon the dissemination and adoption of present knowledge, willingness to improve capital facilities, and changes in law. Slower or more rapid adoption of water-saving techniques could be assumed, with corresponding changes in assumed water use.

From the standpoint of the country as a whole, however, irrigation water requirements are expected to rise. Losses were estimated as growing from 5,200 million gallons per day to 25,000 million gallons per day in the 13 eastern regions (table 19).

TABLE 19.—*Losses: Eastern irrigation, western irrigation, 1954 and 2000*

[In million gallons per day]

	Eastern United States		Western United States	
	1954	2000	1954	2000
New England	61	280		
Delaware and Hudson	192	452		
Chesapeake Bay	113	1,245		
Southeast	1,445	8,123		
Eastern Great Lakes	82	605		
Western Great Lakes	155	1,160		
Ohio	202	1,811		
Cumberland	18	108		
Tennessee	63	320		
Upper Mississippi	295	4,614		
Lower Mississippi	1,242	2,097		
Upper Missouri			13,617	19,936
Lower Missouri	105	1,418		
Upper Arkansas-White-Red			3,648	4,393
Lower Arkansas-White-Red	1,237	2,961		
Western Gulf			9,100	9,743
Upper Rio Grande and Pecos			5,052	4,745
Colorado			15,570	13,120
Great Basin			7,259	6,006
Pacific Northwest			12,436	13,509
Central Pacific			27,609	24,320
South Pacific			3,875	3,010
Total	5,210	25,194	98,166	98,782

TABLE 20.—*All losses: Withdrawal uses gross land treatment and structure losses, and fish and wildlife, 1954*[1]

[In million gallons per day]

	Withdrawal uses	Land treatment and structures	Fish and wildlife	Total
New England	371	333	417	1,121
Delaware and Hudson	626	−123	1,268	1,771
Chesapeake Bay	293	38	869	1,200
Southeast	1,907	365	19,940	22,212
Eastern Great Lakes	400	50	1,105	1,555
Western Great Lakes	587	54	3,614	4,255
Ohio	722	213	178	1,113
Cumberland	26	71	48	145
Tennessee	133	116	66	315
Upper Mississippi	562	159	4,861	5,582
Lower Mississippi	1,403	154	9,453	11,010
Upper Missouri	13,972	966	17,696	32,634
Lower Missouri	134	115	14	263
Upper Arkansas-White-Red	3,956	229	1,146	5,331
Lower Arkansas-White-Red	1,379	261	1,924	3,564
Western Gulf	10,043	191	12,566	22,800
Upper Rio Grande and Pecos	5,114	92	1,490	6,696
Colorado	15,662	59	2,559	18,280
Great Basin	7,350	12	5,306	12,668
Pacific Northwest	12,734	140	1,149	14,023
Central Pacific	27,923	53	3,757	31,733
South Pacific	4,192		32	4,224
United States	109,489	3,548	89,458	202,495

[1] Losses for land treatment and structures and fish and wildlife habitat are assumed to have already been reflected in runoff and therefore would not be charged against runoff.

---

[9] These are increases over 1954. Most of the discussion about basic economic indexes in an earlier section of this part dealt with changes between 1960 and 2000. Carrying the indexes back to 1954 will explain part of the percentage growth in water use; the change in industrial mix implied by the projections of output will explain the remainder.

[10] Evaporation loss per kilowatt-hour is greater in the West than in the Nation as a whole.

[11] Losses were assumed to be 10 percent of intake in the East and 20 percent in the West.

Tables 21 and 22 show total projected losses from each region when increased onsite use of water is added to losses from withdrawal uses.[12] Water loss induced by soil and moisture conservation practices are comparatively small. For the country as a whole, loss from this is less than 1 percent of runoff. In some of the western regions, however, projected requirements by 2000 amount to about 5 percent of average supply. It is likely that this overstates *net* requirements for some regions, since the reduction in erosion, sedimentation, and deposition resulting from a successful program of holding soil in place is likely to reduce nonbeneficial consumption by phreatophytes and excessive evaporation in stream channels modified by heavy deposition.

TABLE 21.—*All losses: Withdrawal uses and increase over 1954 for land treatment and structures and fish and wildlife habitat, 1980*

	With-drawal uses	Increase over 1954		Total
		Land treatment and structures	Fish and wildlife	
New England	803	441	307	1, 551
Delaware and Hudson	1, 183	−86	953	2, 050
Chesapeake Bay	685	147	661	1, 493
Southeast	4, 036	486	14, 880	19, 402
Eastern Great Lakes	849	134	786	1, 769
Western Great Lakes	1, 447	59	2, 744	4, 250
Ohio	1, 704	350	113	2, 167
Cumberland	49	83	37	169
Tennessee	317	122	49	488
Upper Mississippi	1, 173	276	3, 594	5, 043
Lower Mississippi	2, 216	165	7, 090	9, 471
Upper Missouri	15, 316	658	13, 149	29, 123
Lower Missouri	258	161	10	429
Upper Arkansas-White-Red	4, 319	201	837	5, 357
Lower Arkansas-White-Red	2, 167	275	1, 511	3, 953
Western Gulf	10, 831	206	9, 417	20, 454
Upper Rio Grande and Pecos	5, 128	100	1, 101	6, 329
Colorado	15, 052	53	1, 951	17, 056
Great Basin	6, 923	5	3, 945	10, 873
Pacific Northwest	13, 018	93	826	13, 937
Central Pacific	27, 810	73	2, 751	30, 634
South Pacific	3, 976	3	18	3, 997
United States	119, 260	4, 005	66, 730	189, 995

TABLE 22.—*All losses: Withdrawal uses and increase over 1954 for and treatment and structures and fish and wildlife habitat, 2000*

	With-drawal uses	Increase over 1954		Total
		Land treatment and structures	Fish and wildlife	
New England	1, 586	493	417	2, 496
Delaware and Hudson	1, 942	−188	1, 284	3, 038
Chesapeake Bay	2, 107	88	934	3, 129
Southeast	11, 813	850	19, 938	32, 601
Eastern Great Lakes	1, 864	18	1, 105	2, 987
Western Great Lakes	4, 104	114	3, 614	7, 832
Ohio	4, 212	528	177	4, 917
Cumberland	199	124	46	369
Tennessee	785	267	66	1, 118
Upper Mississippi	5, 571	559	4, 861	10, 991
Lower Mississippi	3, 671	314	9, 456	13, 441
Upper Missouri	20, 958	1, 505	17, 632	40, 095
Lower Missouri	1, 552	237	18	1, 807
Upper Arkansas-White-Red	5, 642	328	1, 146	7, 116
Lower Arkansas-White-Red	3, 708	661	1, 988	6, 357
Western Gulf	15, 315	549	12, 820	28, 684
Upper Rio Grande and Pecos	5, 094	137	1, 490	6, 721
Colorado	14, 453	96	2, 624	17, 173
Great Basin	6, 489	12	5, 306	11, 807
Pacific Northwest	15, 033	171	1, 155	16, 359
Central Pacific	26, 019	96	3, 757	29, 872
South Pacific	4, 228	3	32	4, 263
United States	156, 345	6, 962	89, 866	253, 173

Of the two classes of onsite loss the larger increase in water loss comes from the projected increase in wildlife habitat for game waterfowl and other birds, mammals, and fish who find swamps and wetlands an agreeable place to live. As already noted, the estimates of water loss are a function of the projected increase in hunters, with bag limits assumed to remain at present restricted levels. If ducks and geese per hunter are to remain constant, however, it will be necessary to supplement the projected increase in U.S. habitat with a corresponding growth in Canadian breeding areas, and perhaps in Mexican wintering grounds.

On the basis of present waterfowl habits and genetic strains, it is believed that wildlife population cannot be increased by any technique other than an increase in habitat. If, therefore, water is not available for the projected increase in supply of wildlife—mainly ducks and geese—the inevitable result will be a lower availability of game birds, reduced shooting opportunities, and reduced harvest. It is not, of course, the reduced supply of food but the reduced availability of sport that pinches.

Projected requirements for wildlife habitat loom so large that by 1980 the loss from *increases* in habitat will amount to 61 percent of total withdrawal losses experienced in 1954. Without any increase in habitat between now and 1980, prospective evapotranspiration losses would be 123,000 million gallons per day—or about 13 percent greater than reductions in surface runoff induced by water use in 1954. With provision for increased habitat, water losses from runoff rise to 190,000 million gallons per day, or 74 percent greater than losses from runoff in 1954.

The rate at which habitat requirements are projected to grow is much greater in the next 20 years than in the subsequent two decades; whereas other uses are expected to grow more evenly over the four decades. In addition to this chronological aberration, the geographic incidence is quite uneven, based upon the expectation that habitat must be provided along flyways now in use if it is to serve its purpose. The unfortunate consequence of avian habit is that relatively heavy demands are placed upon a few regions. The three most important regions, measured by water requirements are Southeast, Upper Missouri, and Western Gulf, in that order. While the Southeast can meet its quota without great difficulty, neither Upper Missouri nor Western Gulf, especially the former, can supply the projected habitat without substantial curtailment of other uses.

---

[12] Losses for 1980 and 2000 are measured as the absolute quantity of withdrawal losses plus the increments over 1954 in onsite losses. The sum can be compared with runoff before depletion to ascertain adequacy of supply.

Projected changes in the demand for water: Flows

The flow uses of water are shown in tables 24 to 28. Navigation and hydroelectric requirements were projected at a single level of use, based upon information regarding future projects. Requirements for sport fishing habitat are given in table 25. Waste dilution flows are given in table 27, for 1980 and table 28 for 2000, medium projection.

In order to cope with the number of variables that are involved, coupled with the lack of certain facts, several simplifying assumptions have been adopted. The reader can determine for himself the effect of relaxing any of the adopted restrictions. These assumptions are as follows:

1. Hydroelectric requirements cannot be used to stipulate minimum flows, since present installed capacity in most regions is based upon a flow-duration curve that does not reflect a high degree of regulation.

2. Requirements for sport fisheries cannot be considered as establishing a minimum flow requirement until it is demonstrated that lakes and reservoirs will not serve as reasonably adequate substitutes.[13] For purpose of this report it is assumed that lakes and reservoirs *will* serve as substitutes.

3. Even if losses exceed runoff, it cannot be concluded that flows required for hydroelectric power cannot be met, since power installations might be above the points of depletion. Until we have information regarding intraregional location of powersites, available runoff at sites before depletion, and total losses within the drainage area above powersites, the matter of water availability for power production is indeterminate.

4. For the same reason as given for hydroelectric power, it cannot be concluded that water requirements for sport fishing will not be met if losses exceed runoff.

5. Minimum required flows would technically be fixed by the larger of waste dilution or navigation requirements plus losses from withdrawal and onsite uses. For the reasons given in Part II, it was decided that required flows would be defined by waste dilution requirements even in those special instances in which navigation flows were greater, namely, in 1980 for Lower Mississippi and Lower Missouri at whatever levels of waste treatment were adopted, and in the Southeast, Upper Mississippi, Lower Arkansas-White-Red and Pacific Northwest for the upper ranges of waste treatment.

Since no minimum flows are stipulated for hydroelectric power no storage requirements beyond those needed for waste dilution plus losses are considered to be necessary. It should be noted, however, that this is a consequence of the first of our assumptions given above and is not necessarily correct. Storage may be needed in particular cases, not only for specific flow regulation for hydropower but also to provide head. As more data become available on a regional basis, conclusions that rest only upon the need to regulate minimum flow can be modified.

It is quite possible that the main chain of cause and effect as it relates to hydroelectric storage requirements may move in the opposite direction from that implied in the previous paragraph. That is, an increase in stream regulation for other purposes may make it desirable to add power capacity beyond the limits that had initially been considered to be feasible. Also, it may be desirable to incorporate hydropower into base load in some situations where it had previously provided only peaking power. The presence of either or both of these effects may indicate that power production beyond the amounts initially shown in table 23 may be a joint benefit with flow regulation.

---

[13] It is hoped that data bearing on this point can be supplied by the U.S. Fish and Wildlife Service, Department of the Interior, once the location and other specifications of prospective reservoirs are known.

Table 23.—*Estimated generation of hydroelectric power by utilities, based on average water conditions*

[In kilowatt-hours]

	1954	1980	2000
	Millions	*Billions*	*Billions*
New England	4,554	5	6
Delaware and Hudson	1,718	2	2
Chesapeake Bay	2,806	4	5
Southeast	4,905	14	19
Eastern Great Lakes	7,999	24	28
Western Great Lakes	2,653	3	3
Ohio	1,015	4	4
Cumberland	1,244	3	4
Tennessee	11,272	16	16
Upper Mississippi	2,733	4	4
Lower Mississippi	0	0	0
Upper Missouri	4,057	16	21
Lower Missouri	113	1	1
Upper Arkansas-White-Red	214	0	1
Lower Arkansas-White-Red	535	5	8
Western Gulf	452	1	1
Upper Rio Grande and Pecos	23	0	0
Colorado	6,986	19	27
Great Basin	1,254	2	2
Pacific Northwest	37,219	128	173
Central Pacific	15,218	28	35
South Pacific	99	0	0
United States	107,069	279	360

Source: Federal Power Commission, Bureau of Power, Dec. 17, 1959.

Table 24.—*Hydroelectric water requirements, 1954, 1980, and 2000*

[In million gallons per day]

	1954	1980	2000
New England	29,460.4	26,782.2	26,782.2
Delaware and Hudson	8,927.4	9,820.1	9,820.1
Chesapeake Bay	20,533.0	24,104.0	31,245.9
Southeast	30,353.2	59,813.6	66,955.5
Eastern Great Lakes	46,422.5	101,772.4	101,772.4
Western Great Lakes	33,031.4	35,709.6	35,709.6
Ohio	16,962.1	35,709.6	35,709.6
Cumberland	5,356.4	13,391.1	13,391.1
Tennessee	24,104.0	33,924.1	33,924.1
Upper Mississippi	32,138.6	29,460.4	32,138.6
Upper Missouri	4,463.7	23,211.2	24,996.7
Lower Missouri	892.7	5,356.4	6,249.2
Upper Arkansas-White-Red		3,571.0	3,571.0
Lower Arkansas-White-Red	5,356.4	29,460.4	29,460.4
Western Gulf	1,785.5	8,034.7	8,034.7
Upper Rio Grande and Pecos		892.7	892.7
Colorado	8,927.4	9,820.1	9,820.1
Great Basin	892.7	2,678.2	2,678.2
Pacific Northwest	93,737.7	133,018.3	133,911.0
Central Pacific	11,605.6	29,460.4	29,460.4
United States	374,050.8	615,990.5	636,523.5

Projected uses and available runoff

The simplest of all relations between supply and demand is a comparison between runoff and projected losses per unit of time. This has been done in table 29. The table reveals the following relations between losses and low flows:

(1) *If we ignore the matter of water quality* we can conclude that up to now there has been no serious imbalance between supply and demand during periods of low flow, except in the nine western regions and to some degree in the Lower Arkansas-White-Red.[14]

(2) Western regions have been able to meet water requirements during periods of low flow only by making use of ground water and surface storage. Except for the Pacific Northwest, low flow runoff is no more than a tenth, and in some instances much less, of current losses in the regions west of the 100th meridian.

(3) By 1980 projected losses will exceed current low flows in Lower Mississippi [15] in addition to the nine western regions and Lower Arkansas-White-Red.

Table 25.—*Sport fishing habitat: Flows, 1954, 1980, 2000*

[In million gallons per day]

	1954	1980	2000
New England	6,200	10,300	12,900
Delaware and Hudson	8,000	17,500	23,400
Chesapeake Bay	9,800	23,200	33,000
Southeast	2,700	9,800	13,900
Eastern Great Lakes	9,600	20,100	28,000
Western Great Lakes	10,000	19,200	27,700
Ohio	4,000	7,100	9,800
Cumberland	500	900	1,100
Tennessee	1,200	2,600	3,100
Upper Mississippi	4,500	8,900	11,100
Lower Mississippi	1,000	2,200	2,500
Upper Missouri	4,300	7,600	9,400
Lower Missouri	1,200	1,800	2,100
Upper Arkansas-White-Red	1,100	1,800	2,200
Lower Arkansas-White-Red	1,300	1,800	1,900
Western Gulf	800	2,400	3,500
Upper Rio Grande and Pecos	700	1,800	2,900
Colorado	3,300	10,000	15,900
Great Basin	800	2,400	4,000
Pacific Northwest	3,100	5,600	8,700
Central Pacific	3,300	11,700	20,600
South Pacific	600	2,300	3,700
United States	78,000	171,000	241,400

Table 26.—*Fresh water navigation flow requirements, 1959, 1980, 2000* [1]

[In million gallons per day]

	1959	1980	2000
Southeast	12,200	19,200	19,200
Eastern Great Lakes	1,300	1,600	1,600
Ohio	600	1,200	1,500
Cumberland	65	97	162
Tennessee		800	800
Upper Mississippi	45,200	48,500	48,500
Lower Mississippi	90,500	97,100	97,100
Lower Missouri	22,600	22,600	22,600
Lower Arkansas-White-Red	4,300	7,400	7,200
Western Gulf		1,400	1,700
Pacific Northwest	100,800	35,200	37,800
Central Pacific	3,300	3,300	3,300
United States	281,000	238,000	221,400

[1] Tentative estimate, unduplicated totals for each region. No figures given where channels are in tidewater reaches. Where no estimates were made for 2000, it was assumed that 1980 requirements would apply.

---

[14] Low flow in the Lower Arkansas-White-Red can be supplemented by contributions from the Upper Arkansas-White-Red if periods of low flow for the respective regions do not coincide.

[15] Exclusive of contributions to main-stem flow from upstream regions.

(4) By the year 2000, projected losses will exceed current low flows in Eastern Great Lakes, Upper Mississippi, Lower Mississippi, Lower Missouri, and the nine western regions. Not only does this fact presage a problem of water availability and quality, but it also warns of possible adverse effect on commercial fisheries dependent upon estuarine waters. Another critical relationship in water demand and supply interaction is that of projected losses to average runoff. When it is indicated that the losses will be greater than the runoff, the anticipated uses cannot all be accomplished unless the region's water supply is augmented, or unless a decrease in rate of loss per unit of output can be induced beyond the reductions already assumed in our computations. Since growth in water use (especially withdrawal uses, sport fishing, navigation and waste dilution) implies a need for increased regularity of flow, a further adjustment must be made in supply data to account for reservoir losses. This adjustment has been made in

TABLE 27.—*Waste dilution flows, 1980, to yield a dissolved oxygen content of 4 milligrams per liter*

[In million gallons per day]

Water resource region	Percent treatment [1]						
	97.5/97.5	95/95	90/90	80/80	70/70	70/60	70/50
New England	8,930	12,700	25,400	50,500	76,700	96,900	115,400
Delaware and Hudson	11,970	11,440	11,700	22,200	34,800	39,300	43,400
Chesapeake Bay	13,790	13,200	22,500	44,700	67,300	80,500	96,400
Southeast	19,560	18,700	17,000	33,000	49,800	55,950	62,100
Eastern Great Lakes	14,610	13,980	25,800	53,000	76,400	90,100	102,900
Western Great Lakes	33,400	31,900	61,000	102,000	183,000	216,000	252,000
Ohio	24,950	23,750	21,650	18,000	14,800	15,620	17,215
Cumberland	1,975	1,885	2,000	4,100	6,100	7,500	8,900
Tennessee	4,010	3,840	6,900	13,950	19,725	23,850	29,850
Upper Mississippi	14,610	13,990	25,272	49,734	74,736	87,588	100,656
Lower Mississippi	4,840	4,630	4,210	6,000	8,700	10,740	12,720
Upper Missouri	4,540	4,352	7,400	14,700	24,400	29,500	34,700
Lower Missouri	2,243	2,145	1,950	1,800	2,730	3,150	3,600
Upper Arkansas-White-Red	2,610	3,800	7,500	15,100	22,900	25,300	28,000
Lower Arkansas-White-Red	4,440	4,260	3,865	7,200	10,900	12,900	14,800
Western Gulf	9,070	8,670	10,300	20,400	30,700	35,800	43,400
Upper Rio Grande and Pecos	1,000	2,200	4,200	8,600	12,800	14,900	17,100
Colorado	2,332	2,229	3,000	5,925	8,850	9,600	10,350
Great Basin	1,200	2,300	4,500	9,200	13,500	17,300	21,200
Pacific Northwest	16,980	16,230	14,760	15,100	22,100	28,900	33,700
Central Pacific	6,000	5,725	5,200	7,900	11,900	13,800	15,700
South Pacific	6,930	6,644	11,800	23,700	35,900	39,800	43,600
United States	210,040	208,570	297,907	526,809	808,741	954,998	1,107,691

[1] The 1st number is the level of biological treatment given to municipal sewage; the 2d number is the level of treatment given to industrial wastes.

TABLE 28.—*Waste dilution flows, 2000, to yield a dissolved oxygen content of 4 milligrams per liter*

[In million gallons per day]

	Percent treatment [1]						
	97.5/97.5	95/95	90/90	80/80	80/70	80/60	80/50
New England	16,920	25,300	50,700	99,100	143,600	187,100	228,400
Delaware and Hudson	18,100	17,310	16,720	33,920	41,280	48,160	55,760
Chesapeake Bay	24,900	23,820	35,112	72,660	94,836	119,280	142,800
Southeast	38,400	35,600	32,350	55,725	66,825	76,725	88,500
Eastern Great Lakes	23,700	26,000	51,900	101,600	134,500	167,300	199,100
Western Great Lakes	53,500	51,200	63,000	127,000	161,000	199,000	234,000
Ohio	39,200	37,550	34,100	27,900	23,200	25,080	29,370
Cumberland	3,898	3,717	3,400	6,900	9,100	12,300	15,000
Tennessee	7,830	7,470	14,700	28,575	40,200	51,000	63,675
Upper Mississippi	22,700	21,750	38,880	77,112	99,846	121,770	144,936
Lower Mississippi	13,030	12,460	11,320	16,080	22,620	29,160	35,640
Upper Missouri	11,500	10,990	11,400	23,000	30,700	39,300	47,100
Lower Missouri	3,980	3,820	3,440	3,210	4,260	5,280	6,390
Upper Arkansas-White-Red	4,600	5,500	10,800	21,900	26,200	30,600	35,000
Lower Arkansas-White-Red	6,330	6,060	6,200	12,400	16,600	20,900	25.200
Western Gulf	15,600	14,800	20,800	41,800	54,300	68,000	80,500
Upper Rio Grande and Pecos	3,770	3,610	7,400	15,000	18,100	21,400	24,500
Colorado	4,730	4,513	7,050	13,950	17,325	20,625	24,075
Great Basin	1,700	3,400	6,600	12,200	17,600	22,200	26,400
Pacific Northwest	22,380	21,450	19,500	23,200	28,000	41,400	50,900
Central Pacific	11,490	10,980	9,900	16,100	20,300	24,600	28,800
South Pacific	11,400	11,700	23,500	47,300	58,100	68,600	79,500
United States	359,658	359,000	478,772	876,632	1,128,492	1,399,780	1,665,646

[1] See note, preceding table.

the last column of the next table, table 30, in which reservoir losses have been subtracted from yield in order to ascertain the maximum attainable regulated flow. The next to the last column shows the average flow under the historical pattern of storage. Differences between the next to last and last columns measure the additional estimated losses incurred in providing the theoretical quantity of storage needed for full regulation.[16] By combining the information in table 29 with table 30 we can see in which regions maximum net regulated flow will meet projected losses by themselves and projected losses plus waste dilution requirements.

Table 29.—*Projected losses,[1] supply available 95 percent of time under present regulation, average supply [2]*

[In million gallons per day]

	Losses			Supply	
	1954 [3]	1980	2000	95 percent	Average
New England	370	1,500	2,500	6,300	67,000
Delaware and Hudson	630	2,100	3,100	3,200	32,000
Chesapeake Bay	290	1,500	3,100	5,600	52,000
Southeast	1,910	19,400	32,600	21,000	212,000
Eastern Great Lakes	400	1,800	3,000	2,300	40,000
Western Great Lakes	590	4,300	7,900	8,400	42,000
Ohio	720	2,200	4,900	7,400	110,000
Cumberland	26	200	400	1,500	17,000
Tennessee	130	500	1,100	9,000	43,000
Upper Mississippi	560	5,100	11,000	7,800	62,000
Lower Mississippi	1,400	9,500	13,500	[4] 2,100	[4] 49,000
Upper Missouri	13,970	29,200	40,100	1,800	29,000
Lower Missouri	130	400	1,900	419	23,000
Upper Arkansas-White-Red	3,900	5,300	7,100	640	13,000
Lower Arkansas-White-Red	1,380	4,000	6,400	1,000	77,000
Western Gulf	10,040	20,500	28,700	920	46,000
Upper Rio Grande and Pecos	[5] 5,110	6,300	6,700	245	3,550
Colorado	15,600	17,100	17,200	905	13,500
Great Basin	7,350	10,900	11,800	840	10,500
Pacific Northwest	12,730	13,900	16,300	9,700	143,000
Central Pacific	27,920	30,700	29,900	1,300	58,000
South Pacific	4,190	4,000	4,300	116	1,600

[1] Medium projection.
[2] Before depletions.
[3] Withdrawal uses only.
[4] Exclusive of contributions from upstream regions to main-stem flow.
[5] At computed level of irrigation water use.

Table 30.—*Minimum streamflow requirements plus losses, to yield 4 milligrams per liter, 1980 and 2000 [1]*

	Required flows (million gallons per day)		Level of treatment, 2000 (percent)	Average runoff before storage losses (million gallons per day)	Maximum low flow that can be sustained (million gallons per day)
	1980	2000			
New England	10,500	19,500	97.5	67,000	64,700
Delaware and Hudson	13,500	19,800	90.0	32,000	31,100
Chesapeake Bay	14,700	27,000	95.0	52,000	50,800
Southeast	36,400	64,900	90.0	212,000	207,400
Eastern Great Lakes	15,700	26,700	97.5	40,000	38,600
Western Great Lakes	36,200	59,100	95.0	42,000	40,000
Ohio	17,000	28,100	80/70.0	110,000	108,500
Cumberland	2,100	3,800	90.0	17,000	15,500
Tennessee	4,300	8,600	95.0	43,000	42,600
Upper Mississippi	19,100	32,700	95.0	62,000	58,900
Lower Mississippi	13,700	24,800	90.0	49,000	47,500
Upper Missouri	33,600	51,100	95.0	29,000	26,900
Lower Missouri	2,200	5,000	80.0	23,000	14,500
Upper Arkansas-White-Red	7,900	11,700	97.5	13,000	10,500
Lower Arkansas-White-Red	7,900	12,400	95.0	77,000	73,300
Western Gulf	29,200	43,500	95.0	46,000	40,400
Upper Rio Grande and Pecos	7,300	10,300	95.0	3,550	950
Colorado	17,300	21,700	95.0	13,500	10,400
Great Basin	12,100	13,500	97.5	10,500	9,300
Pacific Northwest	28,700	35,800	90.0	143,000	136,300
Central Pacific	35,900	39,800	90.0	58,000	55,300
South Pacific	10,600	15,700	97.5	1,600	320

[1] Assumes that treatment is carried to the point that minimizes the amount of water needed for waste dilution.

Estimated future losses in 1980 exceed maximum net yield in Upper Missouri, Rio Grande, Colorado, Great Basin, and South Pacific. In other words, given the projected demands for water, these regions will find their entire surface water supply lost to the atmosphere before all uses can be met.

Between 1980 and 2000 no new regions join the list of those for which projected losses exceed maximum sustained flow although the aquatic margin is seriously reduced for the Upper Arkansas-White-Red and the Western Gulf.

When we compare the sum of losses and required stream flows, assuming that waste treatment is carried to the point for which dilution requirements are at a minimum, with maximum sustained yields we see that in 1980 required flows can be met in all regions except Upper Missouri, Rio Grande, Colorado, Great Basin, and South Pacific. In other words, all regions that can meet evapotranspiration losses can also meet the additional requirements for waste dilution. By the year 2000, however, the picture is changed by addition of the following: Western Great Lakes, Upper Arkansas-White-Red, and Western Gulf.

The foregoing conclusion rests, it will be noted, on the minimum waste dilution flow that is deemed feasible with present and foreseeable techniques of waste treatment. The levels of treatment associated with these flows average about 95 percent BOD removal, roughly twice that which now prevails. Some authorities believe that it is not realistic to assume treatment in excess of 90 percent. If we adopt a 90 percent ceiling, one more region, Eastern Great Lakes, would be added to the list.

It may seem strange to conclude that the Great Lakes regions are among those with potential water shortage. If the reservoir of water in the lakes themselves is used for waste dilution, the shortage might be eliminated. We do not yet know, however, the capacity of lakes to absorb treated waste, nor the cumulative effects of discharging waste into them at a greater rate than can be handled by the quantity of runoff.

---

[16] In two regions, Rio Grande and South Pacific, maximum net flow is attained before reaching the maximum amount of usable storage computed without reference to storage losses.

In regions of high evapotranspiration loss relative to supply, it is likely that flow regulation will proceed to the highest practicable point, which is here assumed to be the highest net sustained flow capable of attainment, and that waste treatment will be carried to the point where dilution flows are minimized. In order to complete our study of these regions it is necessary to ascertain the potential increments of flow, costs of associated storage, costs of treatment associated with minimum flow requirements, and the likelihood that these costs will be incurred. We shall return to some of these points later in this section.

In three regions—Western Great Lakes, Upper Arkansas-White-Red, and Western Gulf—water supplies exceed projected losses but fall short of the flow required to offset losses and also meet minimum waste dilution requirements. For these regions, as in those for which projected losses by themselves exceeded maximum sustained flows, it was assumed that treatment would be carried to the point that minimized flow needs and that storage would be added to the point of yielding highest net sustained flows. As for the previous groups, our formal analysis would not be complete without a comparison of marginal storage and treatment costs and the uses to be served by the water. This has been reserved for a later study.

In the remaining regions, there is enough water to allow for a choice of storage/treatment combinations. In some regions any combination of treatment and storage, within the adopted limits of treatment, is possible. In others the choice may be limited only to two alternatives.

Table 31 shows what choices will be open to each of the 22 regions in 1980 and 2000. No region fell into the class for which water supply was just equal to losses plus minimum dilution requirements. It is likely that some regions will fall into this category for the high projections in the year 2000.[17]

Three regions change positions between 1980 and 2000: Western Great Lakes, Upper Arkansas-White-Red, and Western Gulf. In 1980 each of these regions has some choice of treatment/storage combinations. By 2000, however, projected water needs exceed average supplies; all choice of treatment/storage combinations is assumed to be eliminated.[18]

TABLE 31.—*Degree of freedom in waste treatment/storage combinations, 1980 and 2000, 4 milligrams per liter*

[O=1980 only; #=2000 only; X=1980 and 2000]

	Water supply less than losses	Water supply less than losses plus minimum water dilution	Water supply equals losses plus minimum water dilution	Water supply more than losses plus minimum water dilution
New England				X
Delaware and Hudson				X
Chesapeake Bay				X
Southeast				X
Eastern Great Lakes				X
Western Great Lakes		#		O
Ohio				X
Cumberland				X
Tennessee				X
Upper Mississippi				X
Lower Mississippi				X
Upper Missouri	X			
Lower Missouri				X
Upper Arkansas-White-Red		#		O
Lower Arkansas-White-Red				X
Western Gulf		#		O
Upper Rio Grande and Pecos	X			
Colorado	X			
Great Basin	X			
Pacific Northwest				X
Central Pacific				X
South Pacific	X			

Another element in the picture should be noted at this point. Waste dilution flows were computed on the assumption that the pattern of waste discharge was proportional to the volume of streamflow. If the pattern of discharge is in fact "lumpy"—i.e., a series of points separated by reaches of river in which no discharge occurs—it was estimated that the total of assimilable waste would have to be reduced by some 30 percent or the quantity of streamflow would have to be increased by some 40 percent in order to have the same effects on water quality. Waste dilution flows required for the Ohio, for example, might be understated by some such magnitude, depending upon the actual pattern of waste discharge. The understatement of required flow would also affect the choice of degree of treatment.

Measures of supply: Physical and cost measures

The basic data used to ascertain present runoff and potential changes in minimum flows are contained in tables 32 to 34, inclusive.

---

[17] Computations not yet completed.

[18] In a wider context, of course, many choices are still open to the eight regions in which water supplies are less than projected requirements. These choices include (1) substitution among uses, (2) net reduction in aggregate of uses, (3) acceptance of lower quality of water, (4) requirement of even a higher dissolved oxygen content accompanied by still further contraction and/or rearrangement of use, (5) importation of water (6) augmentation of water supply by some method other than importation, including mining of ground water for a limited period.

Table 32 gives the flows still available at designated frequencies. Table 33 shows what storage would be required to raise to 100 percent assurance the flows presently available 50 to 95 percent of the time. Table 34 shows flow-storage relationships before depletions for the seven western regions in which current losses are high.

Supplementary estimates were made of the storage required to yield the average flow[19] and the increase in evaporation resulting from increased storage. In estimating evaporation losses from reservoirs, estimated additions to stored

---

[19] By plotting the flow-storage relations on double log paper and extrapolating to average flow.

TABLE 32.—*Present supply of water available*

[In million gallons per day]

	Average supply remaining	Streamflow available for indicated percent of time				
		95 percent	90 percent	80 percent	70 percent	50 percent
New England	67,000	6,300	9,700	16,000	22,000	39,000
Delaware and Hudson	32,000	3,200	4,800	7,800	11,000	19,000
Chesapeake Bay	52,000	5,600	8,400	13,000	18,000	32,000
Southeast	212,000	21,000	31,000	49,000	71,000	126,000
Eastern Great Lakes	40,000	2,300	3,700	6,500	9,700	19,000
Western Great Lakes	42,000	8,400	12,000	16,000	21,000	32,000
Ohio	110,000	7,400	9,400	15,000	21,000	46,000
Cumberland	17,000	1,500	2,100	3,300	4,500	7,800
Tennessee	43,000	9,000	11,000	15,000	19,000	28,000
Upper Mississippi	62,000	7,800	12,000	18,000	25,000	41,000
Lower Mississippi	49,000	2,100	3,600	6,500	10,000	21,000
Upper Missouri	19,000	1,200	1,800	3,200	4,500	9,000
Lower Missouri	23,000	410	550	1,200	2,200	5,800
Upper Arkansas-White-Red	11,000	410	700	1,300	2,100	4,500
Lower Arkansas-White-Red	77,000	1,000	2,100	4,400	8,400	20,000
Western Gulf	46,000	920	1,700	3,400	5,900	14,000
Upper Rio Grande and Pecos	(1)	(1)	(1)	(1)	(1)	(1)
Colorado	3,200	210	320	560	830	1,700
Great Basin	3,700	300	470	780	1,200	2,100
Pacific Northwest	143,000	9,700	21,000	26,000	39,000	76,000
Central Pacific	47,000	1,000	1,900	3,800	6,300	16,000
South Pacific	360	30	40	60	100	180
United States	1,100,000	90,000	140,000	210,000	360,000	560,000

[1] Appropriations currently exceed supply.

Source: Committee Print No. 3.

TABLE 33.—*Storage required to produce selected dependable flows*

	Storage required to produce indicated flow 100 percent of time									
	Flow (million gallons per day)	Storage (thousand acre-feet)	Flow (million gallons per day)	Storage (thousand acre-feet)	Flow (million gallons per day)	Storage (thousand acre-feet)	Flow (million gallons per day)	Storage (thousand acre-feet)	Flow (million gallons per day)	Storage (thousand acre-feet)
New England	6,300	1,300	9,700	1,900	16,000	4,200	22,000	7,300	39,000	26,000
Delaware and Hudson	3,200	590	4,800	900	7,800	2,000	11,000	3,800	19,000	11,000
Chesapeake Bay	5,600	960	8,400	1,400	13,000	3,400	18,000	6,000	32,000	20,000
Southeast	21,000	4,900	31,000	7,800	49,000	14,000	71,000	25,000	126,000	78,000
Eastern Great Lakes	2,300	720	3,700	1,100	6,500	2,200	9,700	3,700	19,000	11,000
Western Great Lakes	8,400	780	12,000	1,100	16,000	2,800	21,000	5,100	32,000	20,000
Ohio	7,400	4,100	9,400	5,200	15,000	7,200	21,000	11,000	46,000	29,000
Cumberland	1,500	160	2,100	290	3,300	620	4,500	1,100	7,800	3,100
Tennessee	9,000	190	11,000	600	15,000	1,200	19,000	2,500	28,000	9,600
Upper Mississippi	7,800	1,100	12,000	2,300	18,000	5,200	25,000	8,700	41,000	26,000
Lower Mississippi	2,100	900	3,600	1,800	6,500	3,200	10,000	5,500	21,000	14,000
Upper Missouri	1,200	340	1,800	660	3,200	1,200	4,500	2,100	9,000	5,700
Lower Missouri	410	660	550	850	1,200	1,300	2,200	2,300	5,800	5,200
Upper Arkansas-White-Red	410	250	700	410	1,300	720	2,100	1,200	4,500	3,000
Lower Arkansas-White-Red	1,000	1,400	2,100	2,500	4,400	5,000	8,400	9,400	20,000	22,000
Western Gulf	920	1,300	1,700	1,700	3,400	3,800	5,900	5,500	14,000	12,000
Upper Rio Grande and Pecos	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Colorado	210	90	320	120	560	230	830	380	1,700	1,200
Great Basin	300	72	470	100	780	240	1,200	420	2,100	1,000
Pacific Northwest	9,700	2,600	21,000	6,600	26,000	9,300	39,000	16,000	76,000	47,000
Central Pacific	1,000	880	1,900	1,700	3,800	3,100	6,300	5,300	16,000	11,400
South Pacific	30	10	40	13	60	26	100	43	180	119
United States	90,000	24,000	140,000	40,000	210,000	71,000	300,000	120,000	560,000	350,000

[1] Appropriations currently exceed supply.

Source: Committee Print No. 3.

TABLE 34.—*Storage required for undepleted flows, selected regions*

Region	Storage required to produce indicated undepleted flows 100 percent of the time											
	Flows now available										Average flow	
	95 percent of time		90 percent of time		80 percent of time		70 percent of time		50 percent of time			
	Flow (million gallons per day)	Storage (thousand acre-feet)	Flow (million gallons per day)	Storage (thousand acre-feet)	Flow (million gallons per day)	Storage (thousand acre-feet)	Flow (million gallons per day)	Storage (thousand acre-feet)	Flow (million gallons per day)	Storage (thousand acre-feet)	Million gallons per day	Storage (thousand acre-feet)
Upper Missouri	1,800	530	2,900	1,100	5,000	1,900	7,100	3,200	14,000	9,000	29,000	30,000
Upper Arkansas-White-Red	640	420	1,070	700	2,000	1,200	3,200	2,000	6,800	5,300	13,000	13,000
Upper Rio Grande and Pecos	245	380	374	500	646	1,000	970	1,600	1,870	5,000	3,550	15,000
Colorado	905	380	1,350	500	2,400	1,000	3,650	1,600	7,100	5,000	13,500	14,500
Great Basin	840	190	1,300	290	2,200	660	3,200	1,100	6,000	2,800	10,500	6,500
Central Pacific	1,300	1,100	2,300	2,200	4,600	3,800	7,750	6,600	18,700	14,000	58,000	38,000
South Pacific	116	4,200	174	60	304	120	450	200	840	540	1,600	1,500

Source: USGS, unpublished

water were converted to equivalent surface area by dividing added capacity by the median depth of reservoirs.[20] Surface area was then multiplied by estimated loss per surface acre.[21] Depths and evaporative losses per surface acre of storage are given in table 35. Table 36 and maps 2–5, inclusive, contain data on characteristics of streams prepared by Roy E. Oltman of the Geological Survey that were used by George Reid in estimating the streamflows needed to provide adequate dilution of wastes (tables 27 and 28).

TABLE 35.—*Median depth of reservoirs and loss by evaporation*

	Median depth (feet)	Loss in feet per acre
New England	19	0.55
Delaware and Hudson	29	.96
Chesapeake Bay	25	.64
Southeast	23	.53
Eastern Great Lakes	16	.68
Western Great Lakes	18	.79
Ohio	24	.47
Cumberland	44	.54
Tennessee	40	.36
Upper Mississippi	7	.83
Lower Mississippi	20	.81
Upper Missouri	25	1.97
Lower Missouri	21	1.11
Upper Arkansas-White-Red	9 (15)	3.27
Lower Arkansas-White-Red	10	1.35
Western Gulf	8 (15)	2.75
Upper Rio Grande and Pecos	20	4.26
Colorado	16	3.79
Great Basin	15	3.00
Pacific Northwest	25	1.44
Central Pacific	33	2.58
South Pacific	44	4.81

Source: Depth computed from USGS, Water Supply Paper 1360-A, Thomas & Harbeck, op. cit. Loss taken from Committee Print No. 13, table 13.

TABLE 36.—*Mean velocity of low flows and average stream length by water resource regions* [1]

Water resource region	Mean velocity (miles per hour)	Average stream length (miles)	Mean depth at velocity given in col. 1 (feet)	Mean flow at velocity given in col. 1 (cubic feet per second)
New England	1½	100	4.0	1,500
Delaware-Hudson	1½	75	3.0	500
Eastern Great Lakes	1½	50	3.0	800
Western Great Lakes	1½	50	3.0	800
Chesapeake Bay	1½	75	5.0	2,500
Ohio	1	100	4.0	1,500
Cumberland	1½	100	3.0	500
Tennessee	1½	75	4.0	1,200
Southeast	1½	150	5.0	2,500
Upper Mississippi	1	150	3.0	500
Lower Mississippi	1½	150	4.0	1,200
Upper Missouri	1½	250	3.0	500
Lower Missouri	1	125	3.5	900
Upper Arkansas-Red	1½	200	2.0	200
Lower Arkansas, Red, and White	1½	175	3.5	1,000
Western Gulf	1	300	4.0	1,500
Rio Grande and Pecos	1½	150	1.5	100
Colorado	1	150	2.0	300
Great Basin	1	100	1.0	50
Pacific Northwest	1	150	4.0	1,500
Central Pacific	1½	100	4.0	1,500
South Pacific	1	50	.5	20

[1] Prepared by Roy E. Oltman, U.S. Geological Survey.

EXPLANATION

Mean velocities of average sized streams for each region have been estimated for discharges of 95-percent time duration through reference to current meter measurement notes allowing for the fact that measurements are not always made at representative cross sections.

Average stream length by regions was estimated from the measured lengths of representative streams in each region. Lengths of streams were measured from headwaters to mouths.

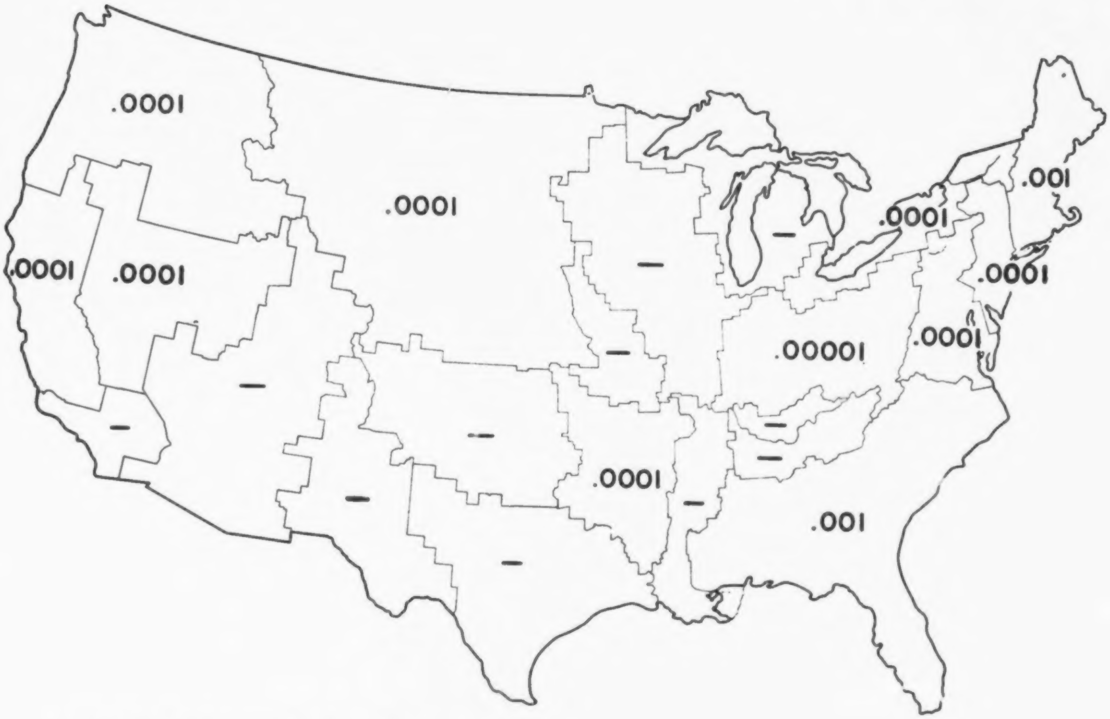
---

[20] As ascertained from Harbeck and Thomas, op. cit.

[21] As ascertained from Committee Print No. 13, op. cit. table 13.

Map 2

Average Ratio of PHOSPHORUS* : DISSOLVED SOLIDS in Streams by Water Resource Regions

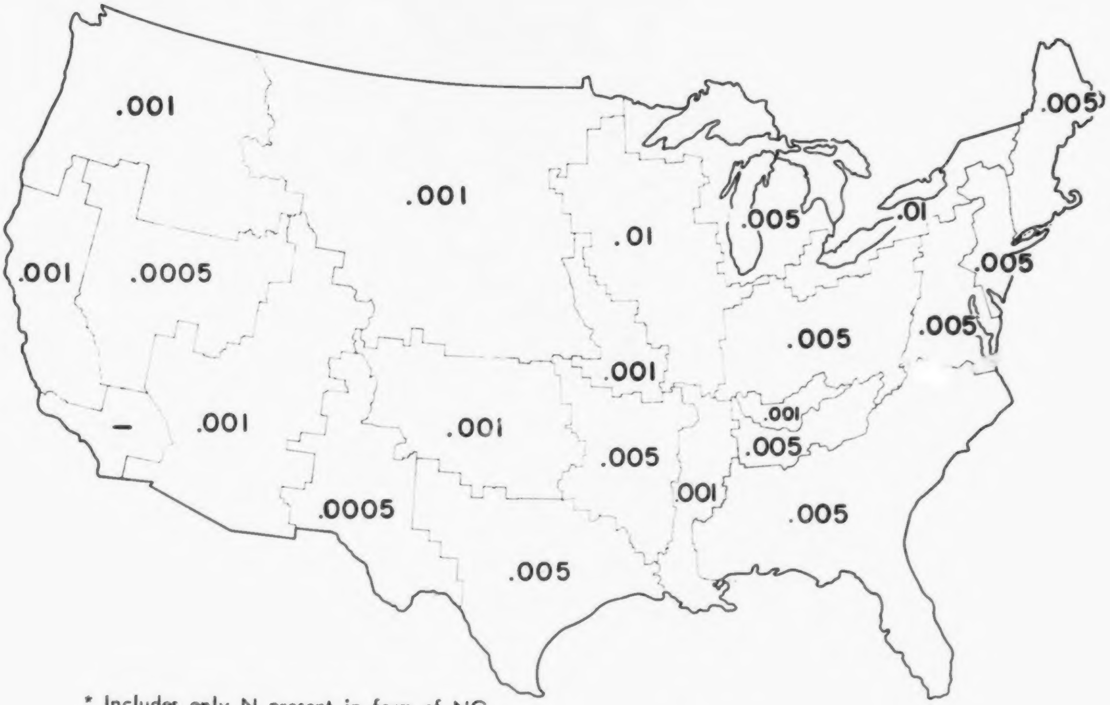

.0001
.0001
.0001
.0001
—
—
—
—
—
.0001
.001
.0001
.0001
—
—
—
.00001
.0001
—
—
.0001
—
.001

* Includes only P present in form of PO_4

Prepared by Roy E. Oltman, U.S. Geological Survey

MAP 3

Average Ratio of NITROGEN* : DISSOLVED SOLIDS in Streams by Water Resource Regions

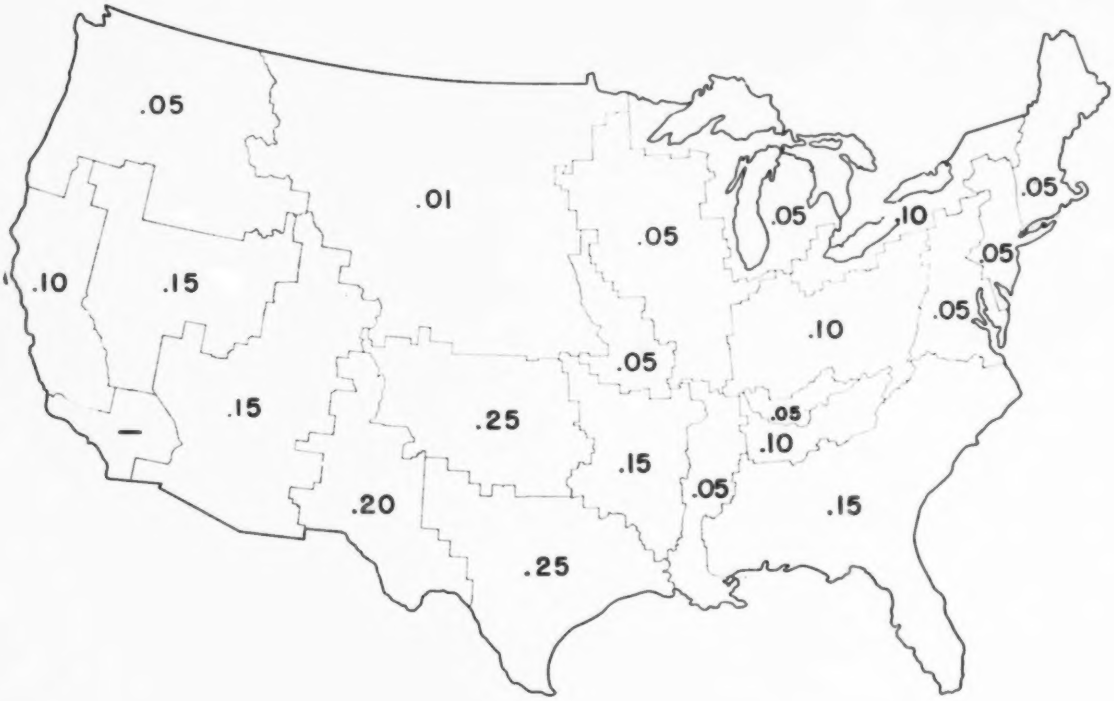

.001
.001
.01
.005
.005
.01
.001
.0005
.005
.005
.005
.001
.001
.001
.001
.005
.005
.001
.005
.0005
.005
.001
.005

* Includes only N present in form of NO_3

Prepared by Roy E. Oltman, U.S. Geological Survey

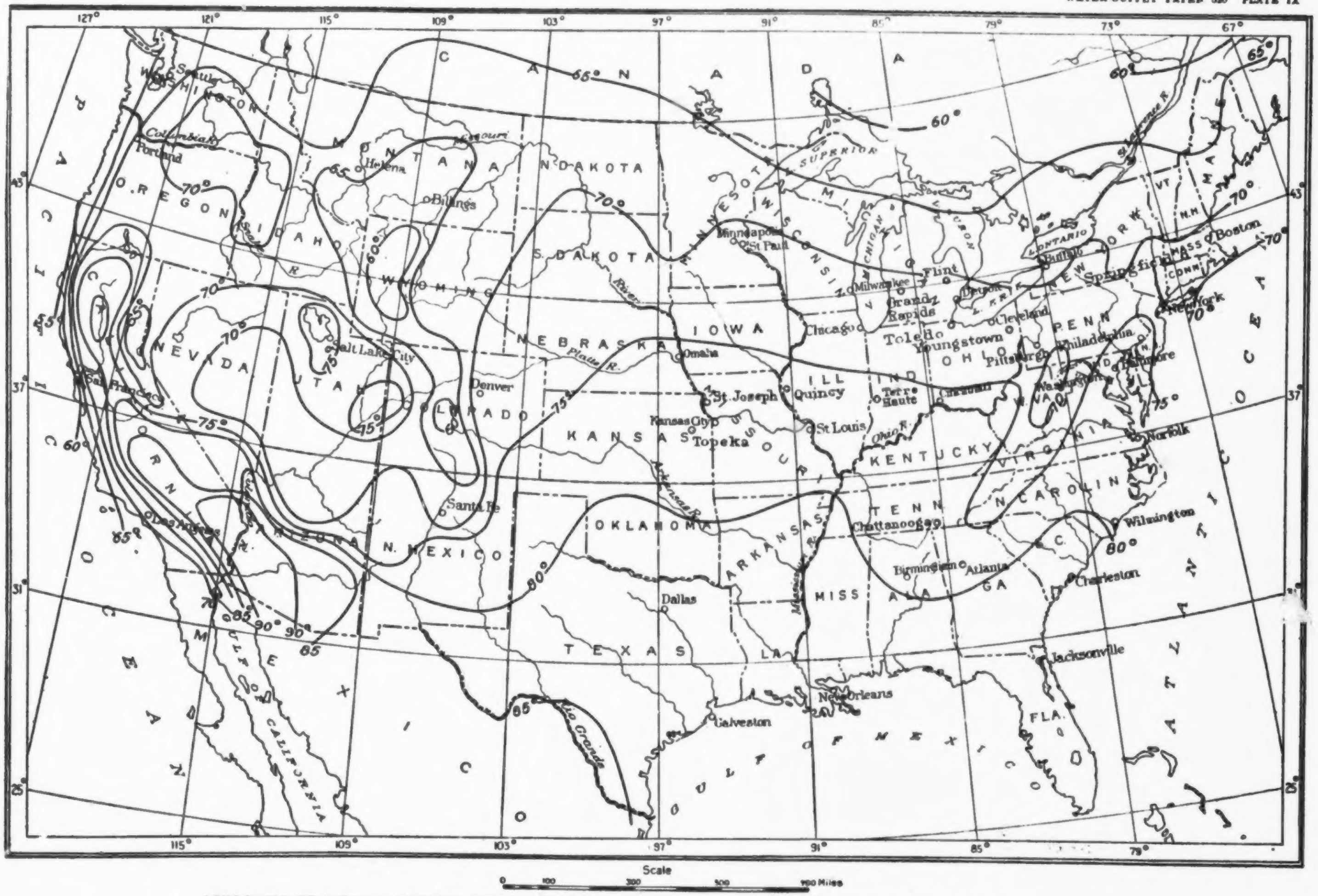
MAP 4

Average Ratio of CHLORIDE: DISSOLVED SOLIDS in Streams by Water Resource Regions


.05
.01
.05
.05
.10
.05
.10
.15
.05
.05
.10
.05
.15
.25
.05
.10
.15
.05
—
.20
.15
.25

Prepared by Roy E. Oltman, U.S. Geological Survey

MAP 5


127°
121°
115°
109°
103°
97°
91°
85°
79°
73°
67°
43°
37°
31°
25°
C A N A D A
P A C I F I C O C E A N
A T L A N T I C O C E A N
G U L F O F M E X I C O
M E X I C O
GULF OF CALIFORNIA
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
COLORADO
ARIZONA
N. MEXICO
N. DAKOTA
S. DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LA.
WISCONSIN
MICHIGAN
ILL
IND
OHIO
KENTUCKY
TENN
MISS
ALA
GA
FLA.
N. CAROLINA
S. C.
VIRGINIA
W. VA.
PENN
NEW YORK
VT
N.H.
MAINE
MASS
CONN
MD.
SUPERIOR
HURON
MICHIGAN
ERIE
ONTARIO
Seattle
Portland
Columbia
Snake R.
San Francisco
Los Angeles
Helena
Billings
Missouri
Salt Lake City
Denver
Santa Fe
Colorado R.
Rio Grande
Platte R.
River
Arkansas R.
Omaha
Kansas City
Topeka
St. Joseph
Quincy
St. Louis
Ohio R.
Minneapolis
St. Paul
Milwaukee
Chicago
Grand Rapids
Flint
Detroit
Toledo
Cleveland
Youngstown
Pittsburgh
Terre Haute
Cincinnati
Buffalo
Springfield
Boston
New York
Philadelphia
Baltimore
Washington
Norfolk
Wilmington
Charleston
Chattanooga
Birmingham
Atlanta
Jacksonville
New Orleans
Galveston
Dallas
St. Lawrence R.
55°
60°
65°
70°
75°
80°
85°
90°
Scale
0
100
300
500
700 Miles

APPROXIMATE MEAN MONTHLY TEMPERATURE OF WATER FROM SURFACE SOURCES FOR JULY AND AUGUST

A distribution of existing (1954) reservoirs by size-class was used as a general pattern. Study of the present distribution (see table 37) revealed that regions containing a relatively large number of reservoirs have representatives of all size classes except the largest.[22] It was also apparent that where a relatively high degree of regulation had been achieved, e.g., Tennessee, Cumberland, Upper Missouri, Upper Arkansas-White-Red, Great Basin, and Colorado,[23] the percent of total storage in large reservoirs was greater than in basins where a small amount of regulation had been achieved. For these reasons the 1954 percentage distribution by size class was not considered appropriate without modification as a guide for the future.[24] Table 38 shows the distribution of capacity by size class that was adopted. No use was made of the largest class (10 million acre-feet and over), and for many regions, none of the smaller classes. Failure to assume construction of reservoirs in excess of 10 million acre-feet contributes an upward bias to the whole cost curve. Failure to include more reservoirs of small capacity introduces a downward bias in marginal costs of the last increments of capacity.

Costs of storage were estimated by increments of storage after taking into account the physiographic region or regions of which a water resource region was composed. By using map 6,[25] an assignment of physiographic regions to water resource regions was made, as shown in table 28. By using the curves shown on chart 1, table 40 was constructed, showing costs per acre-foot by reservoir size and physiographic region.[26]

The effects of putting together the data of tables 38 and 39, map 6, and chart 1 are given in tables 41 and 42. Table 41 shows the estimated cumulative distribution of capacity in each region by size class of reservoir and the cumulative annual costs. Table 42 does the same for the successively higher levels of sustained flow associated with the cumulative capacities shown in table 41. Tables 41 and 42 represent supply schedules of reservoir capacity and of minimum flow.

---

[22] Only Upper Missouri and Colorado had members of the class ranging from 10 million acre-feet upward, e.g., Garrison on the Upper Missouri and Lake Mead on the Colorado.

[23] Measured by ratio of storage to average annual supply. See Committee Print No. 3, op. cit.

[24] Except in New England, where the distribution for 1954 was retained.

[25] Prepared by Howard Cook, Corps of Engineers, to go with chart 1 showing costs of storage by size of reservoir and physiographic region. Chart 2, prepared by Arnold Babb, Bureau of Reclamation, was used for parts of the West.

[26] Table 39 was prepared from an earlier version of map 6 that did not have the physiographic zones for the Rio Grande, Colorado, and Great Basin regions. It was assumed that zone G would serve as an average zone for the three regions. The distributions of tables 38 and 39 are preliminary.

TABLE 37.—*Percentage distribution of reservoirs by size class, 1954*

[Size classes in thousand acre-feet]

Class	10	30	50	80	150	300	700	1,500	3,000	7,000	10,000	Total
Range of class	0–19.9	20–39.9	40–59.9	60–99.9	100–199.9	200–399.9	400–999.9	1,000–1,999	2,000–3,999	4,000–9,999	10,000 and over	
New England	8.8	9.4	7.3	8.3	20.3	15.6	14.6	15.6	0	0	0	100
Delaware and Hudson	5.1	8.8	1.3	12.8	16.0	0	56.0	0	0	0	0	100
Chesapeake Bay	15.2	6.1	0	48.5	30.3	0	0	0	0	0	0	100
Southeast	.9	1.1	1.1	.9	11.3	9.7	18.8	40.3	16.1	0	0	100
Eastern Great Lakes	16.1	9.7	0	25.8	48.3	0	0	0	0	0	0	100
Western Great Lakes	13.7	12.3	10.3	5.5	10.3	0	47.9	0	0	0	0	100
Ohio	1.8	5.0	1.7	14.7	30.1	35.1	11.7	0	0	0	0	100
Cumberland	.1	0	.5	0	1.6	0	7.4	16.0	0	74.4	0	100
Tennessee	.7	.3	.3	.5	5.8	8.3	11.7	16.7	16.7	39.0	0	100
Upper Mississippi	24.6	2.8	4.1	6.5	15.2	18.3	28.4	0	0	0	0	100
Lower Mississippi	.5	0	0	0	0	7.7	53.6	38.3	0	0	0	100
Upper Missouri	.9	.7	.3	1.1	1.9	2.7	5.3	7.6	7.6	8.9	63.2	100
Lower Missouri	0	0	0	0	0	0	0	100	0	0	0	100
Upper Arkansas-White-Red	1.5	1.2	2.4	3.9	4.4	11.7	6.8	0	0	68.2	0	100
Lower Arkansas-White-Red	.2	.5	.3	1.0	.5	6.8	2.3	14.5	29.0	45.0	0	100
Western Gulf	1.2	16.2	.9	.5	7.2	16.2	12.6	27.1	18.0	0	0	100
Upper Rio Grande and Pecos	2.0	2.2	2.4	2.0	11.0	7.3	0	0	73.2	0	0	100
Colorado	.6	.7	.2	.5	3.1	1.8	4.2	8.9	0	0	80.2	100
Great Basin	4.6	5.1	7.3	3.9	11.0	14.6	17.0	36.5	0	0	0	100
Pacific Northwest	1.4	2.1	1.7	3.4	7.3	9.2	17.1	27.5	9.2	21.4	0	100
Central Pacific	2.7	2.4	3.5	4.3	4.1	9.8	19.0	16.3	0	37.9	0	100
South Pacific	7.0	14.3	13.0	7.0	19.6	39.1	0	0	0	0	0	100

Source: Harbeck and Thomas, op. cit.

Table 38.—*Total storage required and percentage distribution of total required capacity as modified, 1980 and 2000*

	Total storage required	Size class (thousand acre-feet)											Total
		10	30	50	80	150	300	700	1,500	3,000	7,000	10,000	
	Thousand acre-feet	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
New England	92,000	8.8	9.4	7.3	8.3	20.3	15.6	14.6	15.6				100
Delaware and Hudson	29,000	5.0	5.0	10.0	15.0	15.0	10.0	20.0	20.0				100
Chesapeake Bay	52,000	5.0	5.0	10.0	15.0	15.0	10.0	20.0	20.0				100
Southeast	77,000		2.0	3.0	10.0	15.0	20.0	50.0					100
Eastern Great Lakes	37,000	5.0	5.0	10.0	25.0	45.0	10.0						100
Western Great Lakes	50,000	10.0	10.0	10.0	10.0	10.0	10.0	30.0	10.0				100
Ohio	40,000	5.0	5.0	5.0	10.0	25.0	30.0	10.0	10.0				100
Cumberland	13,500				5.0	5.0	10.0	10.0	20.0	50			100
Tennessee	44,000			5.0	5.0	10.0	10.0	10.0	20.0	20	20		100
Upper Mississippi	62,500	5.0	10.0	10.0	10.0	15.0	20.0	25.0	5.0				100
Lower Mississippi	41,000				5.0	5.0	10.0	40.0	30.0	10			100
Upper Missouri	30,000				5.0	5.0	10.0	10.0	20.0	20	30		100
Lower Missouri	8,000						25.0	25.0	25.0	25			100
Upper Arkansas-White-Red	9,000		2.0	3.0	4.0	5.0	16.0	20.0	20.0	30			100
Lower Arkansas-White-Red	40,000					5.0	5.0	10.0	30.0	30	20		100
Western Gulf	34,000		1.0	4.0	5.0	10.0	15.0	15.0	30.0	20			100
Upper Rio Grande and Pecos	7,400		2.0	3.0	5.0	10.0	10.0	10.0	10.0	50			100
Colorado	14,500					5.0	5.0	10.0	30.0	50			100
Great Basin	6,500		2.0	3.0	10.0	15.0	20.0	20.0	30.0				100
Pacific Northwest	130,000				5.0	5.0	10.0	10.0	20.0	20	30		100
Central Pacific	38,000				5.0	5.0	10.0	10.0	20.0	20	30		100
South Pacific	650	5.0	5.0	20.0	20.0	20.0	30.0						100

Table 39.—*Percentage distribution of reservoir capacity by physiographic region*

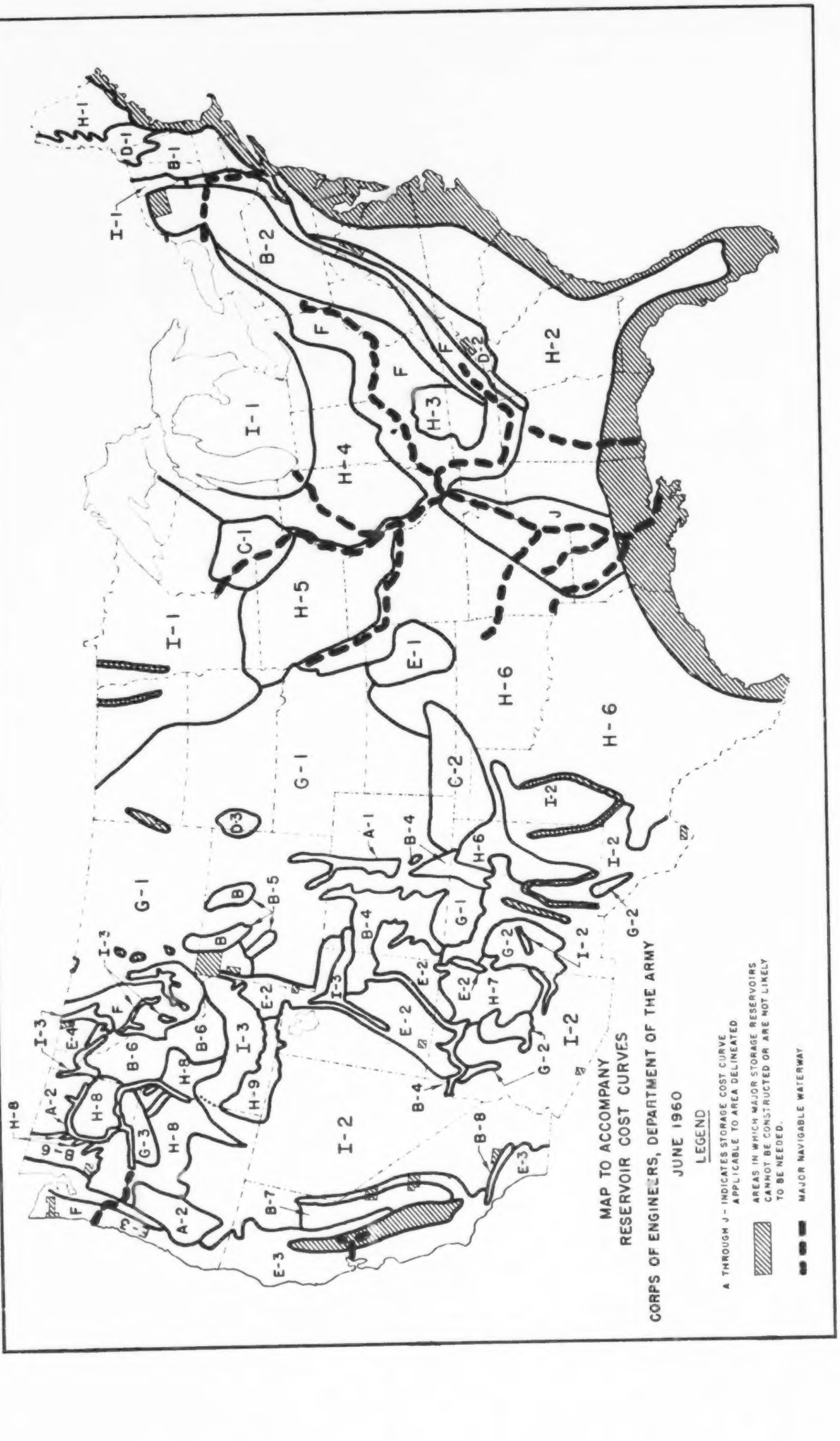
	A	B	C	D	E	F	G	H	I	J	Total
New England		100									100
Delaware and Hudson		100									100
Chesapeake Bay		100									100
Southeast				5				95			100
Eastern Great Lakes								100			100
Western Great Lakes								100			100
Ohio						50		50			100
Cumberland						50		50			100
Tennessee						100					100
Upper Mississippi			20					80			100
Lower Mississippi								50		50	100
Upper Missouri							90		10		100
Lower Missouri					10			90			100
Upper Arkansas-White-Red			10					90			100
Lower Arkansas-White-Red					10			90			100
Western Gulf								100			100
Upper Rio Grande and Pecos							100				100
Colorado							100				100
Great Basin							100				100
Pacific Northwest	100										100
Central Pacific		20			60			20			100
South Pacific					100						100

Table 40.—*Costs of storage per acre-foot by size class of reservoir and physiographic region*

[Size class in thousand acre-feet]

Physiographic region	Size class										
	10	30	50	80	150	300	700	1,500	3,000	7,000	30,000
A	$230	$190	$175	$162	$145	$130	$113	$100	$88	$77	$60
B	200	160	145	132	115	100	85	75	64	55	40
C	180	135	120	110	95	80	66	56	49	40	28
D	160	120	105	93	78	65	52	42	35	28	18
E	155	115	98	85	73	60	47	38	32	25	16
F	145	106	90	80	65	55	43	34	28	21	14
G	140	103	87	75	60	50	38	30	25	19	12
H	120	86	73	62	50	40	30	24	18	14	10
I	95	65	55	46	38	30	22	18	15	10	8
J	65	43	37	32	25	20	15	12	10	8	6

MAP 6


H-1
D-1
B-1
I-1
B-2
F
F
F
D-2
H-2
H-3
I-1
H-4
C-1
J
H-5
I-1
E-1
H-6
H-6
G-1
C-2
D-3
I-2
A-1
B-4
H-6
I-2
G-1
B-5
B
B
I-3
G-1
B-4
E-2
G-2
I-2
G-2
I-3
E-2
E-2
H-7
E-2
I-3
E-4
F
B-6
B-6
I-3
H-8
A-2
H-8
H-8
H-9
I-2
G-2
B-4
H-8
G-3
H-8
I-2
B-8
E-3
B-7
A-2
F
E-3
E-3

MAP TO ACCOMPANY
RESERVOIR COST CURVES
CORPS OF ENGINEERS, DEPARTMENT OF THE ARMY
JUNE 1960

LEGEND

A THROUGH J - INDICATES STORAGE COST CURVE APPLICABLE TO AREA DELINEATED

▨ AREAS IN WHICH MAJOR STORAGE RESERVOIRS CANNOT BE CONSTRUCTED OR ARE NOT LIKELY TO BE NEEDED.

▬ ▬ ▬ MAJOR NAVIGABLE WATERWAY

Chart 1

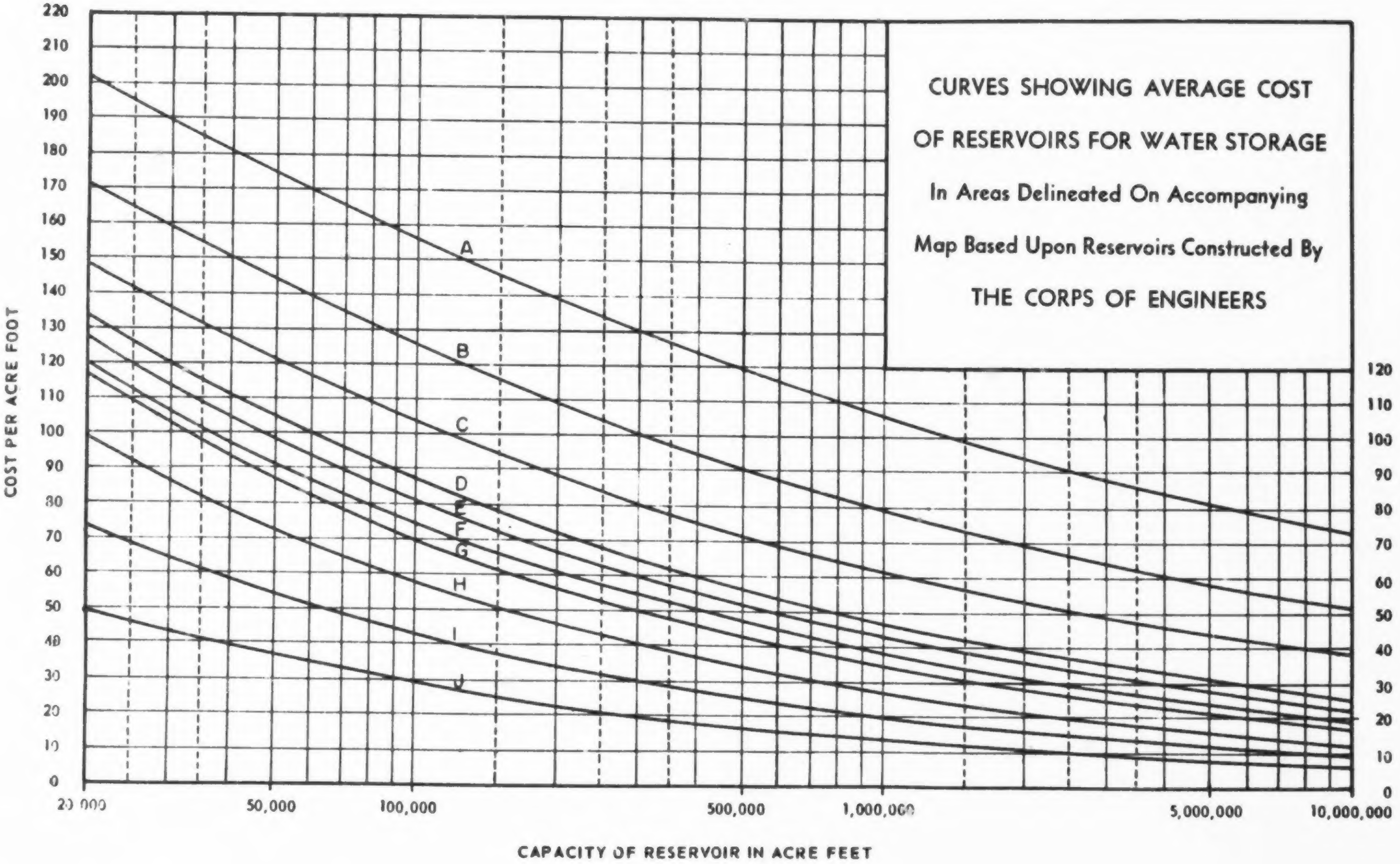

CURVES SHOWING AVERAGE COST
OF RESERVOIRS FOR WATER STORAGE
In Areas Delineated On Accompanying
Map Based Upon Reservoirs Constructed By
THE CORPS OF ENGINEERS
A
B
C
D
E
F
G
H
I
J
COST PER ACRE FOOT
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
20 000
50,000
100,000
500,000
1,000,000
5,000,000
10,000,000
CAPACITY OF RESERVOIR IN ACRE FEET
120
110
100
90
80
70
60
50
40
30
20
10
0

CHART 2

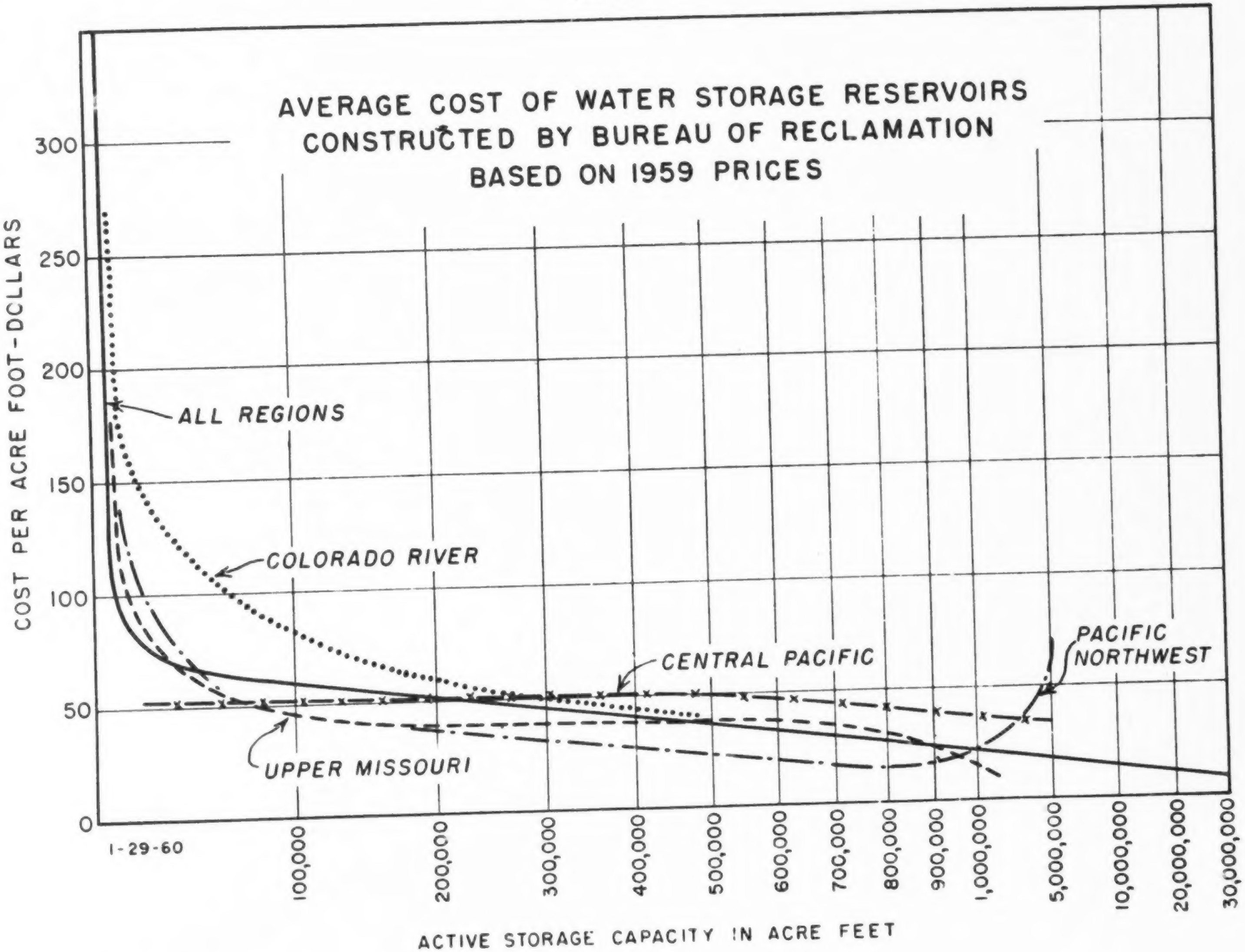

AVERAGE COST OF WATER STORAGE RESERVOIRS
CONSTRUCTED BY BUREAU OF RECLAMATION
BASED ON 1959 PRICES
COST PER ACRE FOOT-DOLLARS
0
50
100
150
200
250
300
ALL REGIONS
COLORADO RIVER
CENTRAL PACIFIC
PACIFIC NORTHWEST
UPPER MISSOURI
1-29-60
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
900,000
1,000,000
5,000,000
10,000,000
20,000,000
30,000,000
ACTIVE STORAGE CAPACITY IN ACRE FEET

Table 41.—*Estimated cumulative capacity and annual costs of storage distributed by region and size class* [1]

Class (thousand acre-feet)	New England		Delaware and Hudson		Chesapeake Bay		Southeast		Eastern Great Lakes		Western Great Lakes	
	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost
	Thousand acre-feet	*Millions*	*Thousand acre-feet*	*Millions*	*Thousand acre-feet*	*Millions*	*Thousand acre-feet*	*Millions*	*Thousand acre-feet*	*Millions*	*Thousand acre-feet*	*Millions*
1,500	14,400	$49	5,800	$20	10,400	$35	----	----	----	----	5,000	$5.4
700	27,900	100	11,600	42	20,800	75	38,500	$54	----	----	20,000	25.7
300	42,300	165	14,500	55	26,000	98	53,900	82	3,700	$6.7	25,000	34.7
150	60,300	258	18,850	77	33,800	139	65,451	109	20,350	44.2	30,000	46.0
80	67,500	301	23,200	103	41,600	185	73,151	131	29,600	70.0	35,000	60.0
50	73,800	342	26,100	122	46,800	219	75,462	139	33,300	82.2	40,000	76.4
30	81,900	400	27,550	132	49,400	238	77,002	145	35,150	89.4	45,000	95.8
10	90,000	473	29,000	146	52,000	261	77,002	145	37,000	99.4	50,000	122.8

Class (thousand acre-feet)	Ohio River		Cumberland		Tennessee		Upper Mississippi		Lower Mississippi		Upper Missouri	
	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost
	Thousand acre-feet	*Millions*	*Thousand acre-feet*	*Millions*	*Thousand acre-feet*	*Millions*	*Thousand acre-feet*	*Millions*	*Thousand acre-feet*	*Millions*	*Thousand acre-feet*	*Millions*
7,000	----	----	----	----	8,800	$8.3	----	----	----	----	8,100	$6.9
3,000	----	----	6,750	$7.0	17,600	19.4	----	----	4,100	$2.6	13,500	13.0
1,500	4,000	$5.3	9,450	10.6	26,400	32.9	3,125	$4.3	16,400	12.5	18,900	20.3
700	8,000	11.9	10,800	12.8	30,800	41.4	18,750	30.5	32,800	29.1	23,000	26.4
300	20,000	37.5	12,150	15.7	35,200	52.3	31,250	57.5	36,900	34.6	26,700	33.7
150	30,000	63.3	12,826	17.5	39,600	65.2	40,625	82.4	38,950	38.1	28,350	37.8
80	34,000	76.1	13,502	19.4	41,800	73.1	46,875	102.6	41,000	42.5	29,820	42.6
50	36,000	83.4	13,502	19.4	44,000	82.0	53,125	125.8	41,000	42.5	29,880	42.7
30	38,000	92.1	13,502	19.4	44,000	82.0	59,375	152.8	41,000	42.5	29,940	42.9
10	40,000	104.0	13,502	19.4	44,000	82.0	62,500	184.9	41,000	42.5	30,000	43.2

Class (thousand acre-feet)	Lower Missouri		Upper Arkansas-White-Red		Lower Arkansas-White-Red		Western Gulf		Rio Grande and Pecos		Colorado	
	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost
	Thousand acre-feet	*Millions*	*Thousand acre-feet*	*Millions*	*Thousand acre-feet*	*Millions*	*Thousand acre-feet*	*Millions*	*Thousand acre-feet*	*Millions*	*Thousand acre-feet*	*Millions*
7,000	----	----	----	----	7,200	$4.5	----	----	----	----	----	----
3,000	1,800	$1.5	3,510	$2.8	18,000	13.2	6,800	$5.5	3,700	$4.1	----	----
1,500	3,600	3.4	5,850	5.3	30,800	27.9	17,000	16.5	4,440	5.1	7,250	$8.1
700	5,400	5.8	8,190	8.5	36,000	35.8	22,100	23.4	5,180	6.4	11,600	13.9
300	7,600	10.1	10,452	13.3	38,000	40.0	27,200	32.6	5,920	8.1	13,050	16.4
150	7,920	11.2	11,427	16.3	40,000	45.1	30,600	40.3	6,660	10.1	13,775	18.0
80	8,000	11.5	12,025	18.2	40,000	45.1	32,300	45.0	7,030	11.4	14,500	20.0
50	8,900	11.5	12,506	20.1	40,000	45.1	33,660	49.5	7,252	12.2	14,500	20.0
30	8,000	11.5	12,870	21.8	40,000	45.1	34,000	50.8	7,400	12.9	14,500	20.0
10	8,000	11.5	13,000	22.9	40,000	45.1	34,000	50.8	7,400	12.9	14,500	20.0

Class (thousand acre-feet)	Great Basin		Pacific Northwest		Central Pacific		South Pacific		United States	
	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost	Cumulative capacity	Cumulative cost
	Thousand acre-feet	*Millions*	*Thousand acre-feet*	*Millions*	*Thousand acre-feet*	*Millions*	*Thousand acre-feet*	*Millions*	*Thousand acre-feet*	*Millions*
7,000	----	----	39,600	$137	6,840	$7.7	----	----	70,540	$164.4
3,000	----	----	66,000	242	11,400	14.3	----	----	153,160	325.4
1,500	1,950	$2.6	92,400	361	23,560	39.0	----	----	300,725	664.2
700	3,250	4.8	105,600	428	28,880	51.7	----	----	469,150	1,027.1
300	4,550	7.7	118,800	505	32,680	62.6	195	$0.5	586,047	1,369.0
150	5,525	10.3	125,400	548	35,340	72.0	325	.9	696,074	1,749.7
80	6,175	12.5	132,000	596	37,088	79.0	455	1.4	766,621	2,046.4
50	6,370	13.3	132,000	596	37,544	81.2	585	2.0	805,386	2,227.3
30	6,500	13.9	132,000	596	37,848	82.9	618	2.2	835,555	2,389.0
10	6,500	13.9	132,000	596	38,000	84.0	650	2.4	860,054	2,582.7

[1] In making the cumulative distribution, it is assumed that largest sites are used first. Costs are total annual costs including amortization.

TABLE 42.—*Estimated cumulative minimum flow net of reservoir losses and cumulative annual costs, distributed by size class, and region* [1]

Class (thousand acre-feet)	New England		Delaware and Hudson		Chesapeake Bay		Southeast		Eastern Great Lakes		Western Great Lakes	
	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost
	Million gallons per day	*Millions*	*Million gallons per day*	*Millions*	*Million gallons per day*	*Millions*	*Million gallons per day*	*Millions*	*Million gallons per day*	*Millions*	*Million gallons per day*	*Millions*
1,500	29,100	$49	13,500	$20	23,100	$35	----	----	----	----	20,300	$5.4
700	39,300	100	19,200	42	32,500	75	88,200	$54	----	----	30,700	25.7
300	47,000	165	21,600	55	36,400	98	103,900	82	9,500	$6.7	33,000	34.7
150	55,000	258	24,800	77	42,300	139	113,700	109	27,000	44.2	34,800	46.0
80	57,800	301	27,600	103	46,000	185	120,500	131	33,900	70.0	36,100	60.0
50	60,100	342	29,200	122	48,800	219	122,400	139	36,200	82.2	37,400	76.4
30	62,900	400	30,200	132	49,800	238	123,400	145	37,700	89.4	38,700	95.8
10	64,800	473	31,100	146	50,700	261	123,400	145	38,600	99.4	40,000	122.8

Class (thousand acre-feet)	Ohio River		Cumberland		Tennessee		Upper Mississippi		Lower Mississippi		Upper Missouri	
	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost
	Million gallons per day	*Millions*	*Million gallons per day*	*Millions*	*Million gallons per day*	*Millions*	*Million gallons per day*	*Millions*	*Million gallons per day*	*Millions*	*Million gallons per day*	*Millions*
7,000	----	----	----	----	26,900	$8.3	----	----	----	----	12,200	----
3,000	----	----	11,700	$7.0	32,900	19.4	----	----	7,600	$2.6	16,700	$13.0
1,500	7,100	$5.3	14,100	10.6	36,900	32.9	13,800	$4.3	22,900	12.5	20,600	20.3
700	15,900	11.9	15,100	12.8	38,600	41.4	34,100	30.5	39,800	29.1	23,200	26.4
300	33,600	37.5	16,000	15.7	39,900	52.3	43,000	57.5	43,700	34.6	25,100	33.7
150	46,500	63.3	16,500	17.5	41,500	65.2	48,500	82.4	45,600	38.1	26,100	37.8
80	51,400	76.1	16,900	19.4	42,100	73.1	51,700	102.6	47,500	42.5	26,700	42.6
50	53,400	83.4	16,900	19.4	42,700	82.0	54,900	125.8	47,500	42.5	26,800	42.7
30	55,800	92.1	16,900	19.4	42,700	82.0	57,600	152.8	47,500	42.5	26,800	42.9
10	58,300	104.0	16,900	19.4	42,700	82.0	58,900	184.9	47,500	42.5	26,900	43.2

Class (thousand acre-feet)	Lower Missouri		Upper Arkansas-White-Red		Lower Arkansas-White-Red		Western Gulf		Upper Rio Grande and Pecos		Colorado	
	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost
	Million gallons per day	*Millions*	*Million gallons per day*	*Millions*	*Million gallons per day*	*Millions*	*Million gallons per day*	*Millions*	*Million gallons per day*	*Millions*	*Million gallons per day*	*Millions*
7,000	----	----	----	----	5,700	$4.5	----	----	----	----	----	----
3,000	1,600	$1.5	4,200	$2.8	14,800	13.2	6,200	$5.5	870	$4.1	----	----
1,500	3,600	3.4	6,000	5.3	25,600	27.9	18,100	16.5	900	5.1	7,500	$8.1
700	5,600	5.8	7,600	8.5	30,200	35.8	24,500	23.4	930	6.4	9,300	13.9
300	8,300	10.1	9,100	13.3	32,000	40.0	31,100	32.6	940	8.1	9,900	16.4
150	8,700	11.2	9,600	16.3	33,300	45.1	35,700	40.3	940	10.1	10,200	18.0
80	8,800	11.5	10,000	18.2	33,300	45.1	37,900	45.0	950	11.4	10,400	20.0
50	8,800	11.5	10,300	20.1	33,300	45.1	39,700	49.5	950	12.2	10,400	20.0
30	8,800	11.5	10,500	21.8	33,300	45.1	40,300	50.8	950	12.9	10,400	20.0
10	8,800	11.5	10,500	22.9	33,300	45.1	40,300	50.8	950	12.9	10,400	20.0

Class (thousand acre-feet)	Great Basin		Pacific Northwest		Central Pacific		South Pacific		United States	
	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost	Cumulative flow	Cumulative cost
	Million gallons per day	*Millions*	*Million gallons per day*	*Millions*	*Million gallons per day*	*Millions*	*Million gallons per day*	*Millions*	*Million gallons per day*	*Millions*
7,000	----	----	66,200	$137	7,500	$7.7	----	----	118,500	$164.4
3,000	----	----	90,100	242	13,600	14.3	----	----	200,270	325.4
1,500	4,400	$2.6	110,200	361	32,200	39.0	----	----	409,900	664.2
700	6,000	4.8	119,600	428	40,200	51.7	----	----	620,530	1,027.1
300	7,400	7.7	127,900	505	46,600	62.6	420	$0.5	726,360	1,369.0
150	8,400	10.3	132,600	548	51,000	72.0	580	.9	813,320	1,749.7
80	9,000	12.5	136,200	596	54,000	79.0	700	1.4	859,450	2,046.4
50	9,300	13.3	136,200	596	54,700	81.2	820	2.0	880,770	2,227.3
30	9,300	13.9	136,200	596	55,200	82.9	860	2.2	895,810	2,389.0
10	9,300	13.9	136,200	596	55,300	84.0	880	2.4	905,740	2,582.7

---

[1] Annual costs including amortization.

Costs of a national water resource program

In order to determine what "should" be the projected water resource program of the 22 regions, it is necessary to compare the variation in storage costs with the variation in treatment costs, for regions in which a choice is possible.

The way in which this was done is illustrated by using the Upper Arkansas-White-Red for 1980. From tables 27 and 28 the waste dilution flow for each level of treatment was determined, and to these were added losses to give total required flows. Tables 43 and 44 give the results. The figures for Upper Arkansas-White-Red are as follows:

Upper Arkansas-White-Red, 1980

[In million gallons per day]

Level of treatment	Waste dilution requirements	Losses	Total required flow
97.5 percent	2,600	5,300	7,900
95 percent	3,800	5,300	9,100
90 percent	7,500	5,300	12,800
80 percent	15,100	5,300	20,400
70 percent	22,900	5,300	28,200
70 percent/60 percent	25,300	5,300	30,600
70 percent/50 percent	28,000	5,300	33,300

Storage requirements for regulated flows within the region's capacity were determined from the flow-storage curve, an adjustment made for reservoir losses, and maximum net yield established. These computations yielded the quantities of storage needed to provide required flows for each level of treatment, up to the maximum regulated flow net of storage losses that could be secured:

Upper Arkansas-White-Red, 1980

Percent treatment	Required flow	Storage before reservoir losses	Storage adjusted to account for reservoir losses
	Million gallons per day	*Thousand acre-feet*	*Thousand acre-feet*
97.5	7,900	7,500	8,000
95.0	9,100	8,000	9,600
(93.0) [1]	10,500	9,500	13,000
90.0	12,800	(2)	(2)
80.0	20,400	(2)	(2)

[1] Interpolated at maximum regulated flow.

[2] Beyond capacity of region.

For each level of treatment, costs of treatment and collection were ascertained from table 45 and table 46.[27]

TABLE 43.—*Total required flows: Losses plus waste dilution, 1980, 4 milligrams per liter* [1]

[Flows in million gallons per day]

Water resource region	Percent treatment						
	97.5/97.5	95/95	90/90	80/80	70/70	70/60	70/50
New England	10,500	14,200	26,900	52,000	78,200	98,400	117,000
Delaware and Hudson	14,100	13,500	13,800	24,300	36,900	41,400	45,500
Chesapeake Bay	15,300	14,700	24,000	46,200	69,[illegible]00	82,000	97,900
Southeast	39,000	38,100	36,400	52,400	[illegible],200	75,300	81,500
Eastern Great Lakes	16,400	15,800	27,600	54,800	78,[illegible]00	91,900	104,700
Western Great Lakes	37,700	36,200	65,300	106,300	187,500	220,300	256,300
Ohio River	27,200	26,000	23,900	20,200	17,000	17,800	19,400
Cumberland	2,200	2,100	2,200	4,300	6,300	7,700	9,100
Tennessee	4,500	4,300	7,400	14,500	20,200	24,400	30,400
Upper Mississippi	19,700	19,100	30,400	54,800	79,800	92,700	105,800
Lower Mississippi	14,300	14,100	13,700	15,500	18,200	20,200	22,200
Upper Missouri	33,700	33,600	36,600	43,900	53,600	58,700	63,900
Lower Missouri	2,600	2,500	2,400	2,200	3,100	3,600	4,000
Upper Arkansas-White-Red	7,900	9,100	12,800	20,400	28,200	30,600	33,300
Lower Arkansas-White-Red	8,400	8,300	7,900	11,200	14,900	16,900	18,800
Western Gulf	29,600	29,200	30,800	40,900	51,200	56,300	63,900
Upper Rio Grande and Pecos	7,300	8,500	10,500	14,900	19,100	21,200	23,400
Colorado	19,400	19,300	20,100	23,000	26,000	26,700	27,500
Great Basin	12,100	13,200	15,400	20,100	24,400	28,200	32,100
Pacific Northwest	30,900	30,100	28,700	29,000	36,000	42,800	47,600
Central Pacific	36,700	36,400	35,900	38,600	42,600	44,500	46,400
South Pacific	10,900	10,600	15,800	27,700	39,900	43,800	47,600
United States	400,400	398,900	488,500	670,400	999,100	1,145,400	1,2[illegible]8,300

[1] Apparent erratic behavior of waste dilution flows, as, e.g., in Ohio, is caused by the combined variations of BOD and algae dilution requirements. See George Reid, op. cit.

---

[27] Treatment costs were estimated by George Reid, op. cit. Collection costs were estimated for municipal waste treatment at $1.30 per capita. The figure of $1.30 per capita was suggested by Kenneth M. Jenkins of Public Health Service.

Table 44.—*Total required flows: Losses plus waste dilution, 2000, 4 milligrams per liter*

[In million gallons per day]

	Percent treatment						
	97.5/97.5	95/95	90/90	80/80	80/70	80/60	80/50
New England	19,453	27,833	53,233	101,633	146,133	189,633	230,933
Delaware and Hudson	21,177	20,387	19,797	36,997	44,357	51,237	58,837
Chesapeake Bay	28,038	26,958	38,250	75,798	97,974	122,418	145,938
Southeast	70,965	68,165	64,915	88,290	99,390	109,290	121,065
Eastern Great Lakes	26,650	28,950	54,850	104,550	137,450	170,250	202,050
Western Great Lakes	61,354	59,054	70,854	134,854	168,854	206,854	241,854
Ohio River	44,113	42,463	39,013	32,813	28,113	29,993	34,283
Cumberland	4,[illegible]	4,088	3,771	7,271	9,471	12,671	15,371
Tennessee	8,946	8,586	15,816	29,691	41,316	52,116	64,791
Upper Mississippi	23,659	32,709	49,839	88,071	110,805	132,729	155,895
Lower Mississippi	26,484	25,914	24,774	29,539	36,074	42,614	49,094
Upper Missouri	51,566	51,056	51,466	63,066	70,766	79,366	87,166
Lower Missouri	5,795	5,635	5,255	5,025	6,075	7,095	8,205
Upper Arkansas-White-Red	11,729	12,629	17,929	29,029	33,329	37,729	42,129
Lower Arkansas-White-Red	12,691	12,421	12,561	18,761	22,961	27,261	31,561
Western Gulf	44,291	43,491	49,491	70,491	82,991	96,691	109,191
Upper Rio Grande and Pecos	10,462	10,302	14,092	21,692	24,792	28,092	31,192
Colorado	21,889	21,672	24,209	31,109	34,484	37,784	41,234
Great Basin	13,512	15,212	18,412	24,012	29,412	34,012	38,212
Pacific Northwest	38,720	37,790	35,840	39,540	44,340	57,740	67,240
Central Pacific	41,343	40,833	39,753	45,953	50,153	54,453	58,653
South Pacific	15,703	16,003	27,803	51,603	62,403	72,903	83,803
United States	612,809	612,151	731,913	1,129,783	1,381,643	1,652,931	1,918,797

Table 45.—*Collection costs plus treatment costs: 1980, 4 milligrams per liter*

[Dollars in millions]

	Urban population (millions)	Collection costs at $1.30 per capita	Total of collection and treatment costs [1]						
			70/50	70/60	70	80	90	95	97 5
New England	9.0	$11.7	$42	$50	$66	$95	$127	$152	$162
Delaware and Hudson	28.2	36.7	85	87	97	128	167	189	200
Chesapeake Bay	11.6	15.1	66	71	93	134	182	213	228
Southeast	16.9	22.0	77	79	90	123	166	189	203
Eastern Great Lakes	15.0	19.5	59	62	73	103	136	156	168
Western Great Lakes	14.9	19.4	89	91	113	163	222	254	271
Ohio River	18.8	24.4	100	104	117	163	222	256	273
Cumberland	.9	1.2	7	8	10	15	20	24	28
Tennessee	2.2	2.9	16	17	23	33	45	52	57
Upper Mississippi	11.0	14.3	67	71	87	125	172	197	212
Lower Mississippi	3.2	4.2	23	25	33	48	65	76	81
Upper Missouri	4.4	5.7	31	34	44	59	82	95	102
Lower Missouri	1.9	2.5	12	12	15	21	29	33	36
Upper Arkansas-White-Red	3.5	4.6	19	20	22	31	41	46	49
Lower Arkansas-White-Red	2.7	3.5	17	18	22	31	43	50	53
Western Gulf	11.3	14.7	62	65	78	109	149	172	183
Upper Rio Grande and Pecos	1.4	1.8	6	6	6	9	12	13	14
Colorado	2.4	3.1	12	12	14	19	25	29	32
Great Basin	1.5	2.0	8	9	12	19	26	29	31
Pacific Northwest	6.2	8.1	49	54	77	108	155	185	197
Central Pacific	12.3	16.0	44	46	53	73	96	110	119
South Pacific	13.6	17.7	45	46	51	67	88	99	107
United States	192.9	251.2	936	1,028	1,196	1,676	2,270	2,619	2,806

---

[1] Total of collection and treatment costs is equal to sum of municipal and industrial treatment costs as estimated for each level of treatment by Reid, *op. cit.*, Appendix, Tables 1-22, plus estimated collection costs computed as the product of urban population and $1.30 per capita.

TABLE 46.—*Collection costs plus treatment costs: 2,000, 4 milligrams per liter*

[Dollars in millions]

	Urban population (millions)	Collection costs at $1.30 per capita	Total of collection and treatment costs [1]						
			80/50	80/60	80/70	80	90	95	97.5
New England	10.9	$14.2	$84	$92	$131	$179	$245	$287	$305
Delaware and Hudson	37.2	48.4	143	147	163	181	237	268	284
Chesapeake Bay	17.6	22.9	127	134	169	212	288	337	359
Southeast	26.4	34.3	167	172	190	213	277	306	326
Eastern Great Lakes	21.4	27.8	119	126	155	192	257	299	331
Western Great Lakes	21.6	28.1	161	169	203	248	338	394	431
Ohio	26.3	34.2	201	209	244	288	384	448	478
Cumberland	1.1	1.4	12	13	18	24	33	39	42
Tennessee	2.9	3.8	34	37	51	68	93	108	118
Upper Mississippi	15.0	19.5	123	129	158	190	263	307	333
Lower Mississippi	4.3	5.6	56	62	89	121	169	198	221
Upper Missouri	5.8	7.5	53	56	72	92	126	144	153
Lower Missouri	2.2	2.9	21	22	28	36	49	57	61
Upper Arkansas-White-Red	4.6	6.0	33	34	38	43	59	73	78
Lower Arkansas-White-Red	3.0	3.9	29	33	40	51	70	81	89
Western Gulf	16.8	21.8	133	140	174	215	292	346	380
Upper Rio Grande and Pecos	2.5	3.3	16	17	18	19	26	29	32
Colorado	4.0	5.2	30	31	36	42	57	66	70
Great Basin	2.6	3.4	14	15	20	27	38	45	48
Pacific Northwest	10.1	13.1	88	96	131	175	241	283	302
Central Pacific	21.2	27.6	101	105	122	142	190	222	252
South Pacific	21.7	28.2	97	100	122	128	168	195	208
United States	279.2	363.1	1,842	1,939	2,372	2,886	3,900	4,533	4,901

[1] See footnote for Table 45.

Costs of storage associated with each level of required flow were taken from table 41. The sum of storage, treatment, and collection costs is the total annual cost of having a supply of water of adequate quality in the stream after allowing for reservoir losses and losses attributable to use. The schedule of costs is as follows:

Upper Arkansas-White-Red, 1980

Percent treament	Storage adjusted for reservoir losses	Treament and collection costs	Storage costs	Total costs
	Thousand acre-feet	*Millions*	*Millions*	*Millions*
97.5	8,000	$49	$8.0	$57.0
95	9,600	46	11.5	57.5
(93) [1]	13,000	44	22.5	66.5
90	(2)	41	(2)	
80	(2)	31	(2)	
Etc.		Etc.		

[1] Interpolated at maximum regulated flow.
[2] Beyond capacity of region.

In the Upper Arkansas-White-Red, both the minimum waste dilution requirement and the minimum cost combination coincided at 97.5 percent treatment. This was not true for all regions. The level of treatment for which total storage, collection, and treatment costs were minimized depended upon the slope of the flow-storage curve, physiographic region, size distribution of reservoir capacity, variation in treatment costs, and interaction of BOD and algal dilution requirements in establishing the level of treatment for which dilution needs are at a minimum.

In the Ohio, to cite a different example, increments of treatment cost were much greater than savings in storage costs as the level of treatment rose. Furthermore, because of the interaction between BOD removal and algal growth, total dilution requirements in the Ohio region were lower at 70 percent/70 percent treatment than at any higher level of BOD removal, as indicated in the following tabulation (losses were 2,200 million gallons per day):

Ohio, 1980

Percent treatment	Waste dilution plus losses	Storage after adjusting for reservoir losses	Collection and treatment costs	Storage costs	Total costs
	Million gallons per day	*Thousand acre-feet*	*Millions*	*Millions*	*Millions*
97.5	27,200	28,000	$273	$58	$331
95	26,000	14,600	256	26	282
90	23,900	13,000	222	22	244
80	20,200	10,800	163	18	181
70	17,000	8,500	117	13	130
70/60	17,800	9,100	104	14	118
70/50	19,400	10,100	100	16	116

As a result of the combined variations in level of treatment, flow requirements, and flow-storage relationships, the low-cost combination is at 70 percent municipal treatment, 50 percent industrial treatment, with a stream flow of 19,400 million gallons per day requiring 10,100,000 acre-feet of storage. If the level of treatment were to be raised to 70 percent municipal, 70 percent industrial, required storage would fall to 8,500,000 acre-feet, lowering storage costs by $3 million. Treatment costs, on the other hand, would rise by $17 million, advancing total costs by $14 million.

Collection costs are constant with variations in treatment level. For the country as a whole, collection costs are roughly a fourth of total treatment and collection costs with treatment at 70 percent/50 percent in 1980, and less than a tenth of combined treatment and collection costs at 97½ percent treatment. Between 1980 and 2000, collection costs are estimated to decline as a fraction of total costs of treatment and collection.

According to table 45, the national outlay for maximum treatment would be almost $3 billion a year by 1980 and rise to almost $5 billion by 2000. At 90 percent treatment, costs would be about $500 million lower in 1980 and $1 billion lower in 2000, than at maximum treatment.

The variation in annual storage costs within each region reveals the marginal cost of storage capacity. For some problems it is more useful to have the data in terms of marginal costs of flow. Such costs can be readily derived from table 42.

On the basis of schedules of storage (or flow) costs and treatment (and collection) costs it is possible to ascertain for each region a combination of storage and treatment that satisfies a designated objective. If agreement can be reached upon the objectives, it is then possible to anticipate the general dimensions of a national water resource program as well as its magnitude within each water resource region.

Costs of alternative water resource programs

In tables 1–6, inclusive, three alternative national water resource programs were described. Each program would meet a particular objective, subject to the limits imposed by the availability of runoff, the projected levels of population, and projected outputs of major water using industries. As many programs can be formulated as people can discern objectives to be met. The three programs selected for illustration are designed, alternatively, to (1) minimize the amount of stream regulation, (2) minimize the combined cost of storage and treatment, (3) minimize the amount of waste treatment. All three programs would yield the same quality of water, measured by the average dissolved oxygen content of the streams of each region, but subject to the limits noted immediately above.

In devising these programs, the range of variability of treatment and storage depended upon projected uses relative to maximum sustained flow. Since certain regions are inadequately endowed with runoff relative to projected uses regardless of the level of treatment, these regions are shown with the same combination of treatment and storage regardless of which objective is sought. For 1980 these regions were Upper Missouri, Rio Grande, Colorado, Great Basin, and South Pacific. For 2000 to these five were added Western Great Lakes, Upper Arkansas-White-Red, and Western Gulf. For the first five the same combination of storage and treatment was assumed to be required in 1980 as in 2000; in other words, full treatment and full development by 1980 based upon projected uses.

Because of the fact that in regions of water shortage the level of output would fall short of projections, it was assumed that national projected output of the products or services in question would fall by a corresponding amount rather than be transferred to another region.

The three alternative programs provide options that meet different combinations of political philosophy, administrative arrangements, and incidence of costs and benefits. The first program, minimum storage, implies that regardless of the fact that different combinations of treatment and storage would, in total, cost less, each region would carry treatment to the point at which streamflow required to yield four parts per million of oxygen would be at a minimum. Total additional storage under this program would amount to about 230 million acre-feet by 1980, roughly four-fifths the present quantity of reservoir capacity. Treatment levels would be at 95 or 97½ percent for 15 regions, at 90 percent for 4, at 80 percent for 1, and at 70 percent for 2, or roughly, twice the present percent of biological treatment. Total annual costs for this program would be about $2.8 billion, divided as follows: Storage, $374 million; collection and treatment, $2.4 billion. By the year 2000, this program would require about 344 million acre-feet of storage over present levels (or about 115 million acre-feet beyond total capacity required by 1980) at an annual cost of storage amounting to some $600 million. Costs of collection and treatment in 2000 would be about $4.1 billion; total annual costs would be almost $4.8 billion.

If the objective were the opposite of minimum storage and maximum treatment; namely, maximum storage and minimum treatment, by 1980 additional regulatory capacity of about 580 million acre-feet would be needed—more than twice the amount needed for a maximum treatment program. Even this would require, however, levels of treatment in non-water-short regions, such as along the Atlantic seaboard, of about 75 percent BOD removal. By the year 2000 total additional storage over present levels would be some 700 million acre-feet. Treatment levels would be as low as 50 percent for industrial waste in only eight regions, and as low as 70 percent in only one. In the remaining 13, it would be between 80 and 90 percent or higher. Such a program would imply annual storage costs by 1980 of about $1.7 billion, and by 2000, about $2 billion. Total annual costs would be $3.3 billion in 1980 and $5.3 billion by 2000. This program, it is seen, would be substantially more expensive than its opposite.

Neither a maximum storage nor a minimum storage program would coincide with a program having as its objective the minimizing of storage, collection, and treatment costs taken together. This third alternative would require somewhat more storage than the minimum storage, maximum treatment combination and, of course, somewhat less treatment. The minimum cost combination would require about 316 million acre-feet of additional storage by 1980 and a further addition of 126 million acre-feet by 2000. Minimum sustained flow would, by the year 2000, be about 604,000 million gallons per day under the minimum cost program, an amount about 116,000 million gallons per day greater than under the minimum storage program but about 204,000 million gallons per day less than required by the maximum storage program. Total sustained flows for all regions in 1980 under the minimum cost program would be the same as total sustained flows in 2000 under the minimum storage program, although there would be discrepancies within a number of regions between the supply of water that was available and what was required. Thus, while a minimum cost program, if adopted for the period 1960–80, would require more regulation than would be needed if treatment were relied upon to the maximum degree, a condition of "over-regulation" would persist for only a comparatively short time.

In addition to the tables in part I, tables 47–51, inclusive, compare specific elements of the three programs: quantity of storage, quantity of flow, cost of storage, cost of collection and treatment, and total costs.

TABLE 47.—*Quantity of additional storage by type of program, 1980, 2000*

[Thousand acre-feet]

	1980			2000			Present storage [1]
	Minimum storage	Minimum cost	Minimum treatment	Minimum storage	Minimum cost	Minimum treatment	
New England	2,400	3,400	90,000	6,100	6,100	90,000	9,000
Delaware and Hudson	5,800	6,100	29,000	12,000	12,000	29,000	3,100
Chesapeake Bay	4,300	11,200	52,000	14,500	14,500	52,000	900
Southeast	9,800	28,000	31,000	21,500	49,000	75,000	16,400
Eastern Great Lakes	8,500	8,500	37,000	20,000	22,800	37,800	500
Western Great Lakes	34,000	34,000	50,000	50,000	50,000	55,000	1,200
Ohio	8,500	10,100	10,100	16,000	20,300	20,300	5,700
Cumberland	300	3,300	4,600	810	7,800	11,000	6,400
Tennessee	120	6,400	13,600	380	12,000	44,000	15,000
Upper Mississippi	5,800	14,000	62,500	17,000	17,000	62,500	4,300
Lower Mississippi	8,500	15,800	15,800	18,000	29,000	41,000	4,500
Upper Missouri	30,000	30,000	30,000	30,000	30,000	30,000	74,800
Lower Missouri	2,350	3,600	4,000	4,900	6,700	7,600	1,200
Upper Arkansas-White-Red	8,000	8,000	13,000	13,000	13,000	13,000	7,300
Lower Arkansas-White-Red	9,600	20,000	22,000	14,600	32,000	38,000	26,800
Western Gulf	25,500	34,000	34,000	34,000	34,000	34,000	11,200
Upper Rio Grande and Pecos	7,400	7,400	7,400	7,400	7,400	7,400	3,300
Colorado	14,500	14,500	14,500	14,500	14,500	14,500	35,100
Great Basin	6,500	6,500	6,500	6,500	6,500	6,500	4,100
Pacific Northwest	10,800	19,200	22,800	14,700	20,400	40,500	28,900
Central Pacific	25,500	31,000	32,000	27,800	36,500	38,000	16,400
South Pacific	650	650	650	650	650	650	1,800
United States	228,829	315,650	582,450	344,340	442,150	741,950	278,000

[1] Usable capacity of reservoirs of 5,000 or more acre-feet, 1954, Committee Print No. 3, table 9.

Table 48.—*Quantity of flow, by type of program, 1980 and 2000*

[Million gallons per day]

	1980			2000		
	Minimum storage	Minimum costs	Minimum treatment	Minimum storage	Minimum costs	Minimum treatment
New England	10, 500	14, 200	65, 000	19, 453	19, 453	65, 000
Delaware and Hudson	13, 500	13, 800	31, 100	19, 767	19, 767	31, 000
Chesapeake Bay	14, 700	24, 000	50, 800	26, 958	26, 958	50, 800
Southeast	36, 400	75, 300	82, 000	64, 915	99, 300	121, 000
Eastern Greak Lakes	15, 800	15, 800	38, 600	26, 650	28, 950	38, 600
Western Great Lakes	36, 200	36, 200	40, 000	40, 000	40, 000	40, 000
Ohio	17, 000	19, 400	19, 400	28, 113	34, 283	34, 300
Cumberland	2, 100	7, 700	9, 100	3, 771	12, 671	15, 400
Tennessee	4, 300	24, 400	30, 400	8, 586	29, 691	42, 600
Upper Mississippi	19, 100	30, 400	58, 900	32, 709	32, 709	58, 900
Lower Mississippi	13, 700	22, 200	22, 200	24, 774	36, 074	49, 100
Upper Missouri	26, 900	26, 900	26, 900	26, 900	26, 900	26, 900
Lower Missouri	2, 200	3, 600	4, 000	5, 025	7, 095	8, 200
Upper Arkansas-White-Red	7, 900	7, 900	10, 500	10, 500	10, 500	10, 500
Lower Arkansas-White-Red	7, 900	16, 900	18, 800	12, 421	18, 761	31, 600
Western Gulf	29, 200	40, 400	40, 400	40, 400	40, 400	40, 400
Upper Rio Grande and Pecos	950	950	950	950	950	950
Colorado	10, 400	10, 400	10, 400	10, 400	10, 400	10, 400
Great Basin	9, 300	9, 300	9, 300	9, 300	9, 300	9, 300
Pacific Northwest	28, 700	42, 800	47, 600	35, 800	44, 300	67, 200
Central Pacific	35, 900	44, 500	46, 400	39, 753	54, 500	55, 300
South Pacific	300	300	300	300	300	300
United States	342, 950	487, 350	663, 050	487, 445	603, 352	807, 750

Table 49.—*Annual costs of storage by type of program, 1980 and 2000*

[In millions of dollars]

	1980			2000		
	Minimum storage	Minimum costs	Minimum treatment	Minimum storage	Minimum costs	Minimum treatment
New England	7	10	473	18	18	473
Delaware and Hudson	18	20	145	43	43	145
Chesapeake Bay	15	36	261	54	54	261
Southeast	15	40	45	32	73	139
Eastern Great Lakes	17	17	99	43	51	99
Western Great Lakes	57	57	123	94	94	94
Ohio	13	16	16	29	39	39
Cumberland	0	3	5	1	8	13
Tennessee	0	6	15	0	12	82
Upper Mississippi	8	26	185	32	32	185
Lower Mississippi	6	12	12	14	25	42
Upper Missouri	43	43	43	43	43	43
Lower Missouri	2	3	10	5	8	10
Upper Arkansas-White-Red	8	8	23	22	22	22
Lower Arkansas-White-Red	6	16	18	10	30	40
Western Gulf	30	51	51	51	51	51
Upper Rio Grande and Pecos	13	13	13	13	13	13
Colorado	20	20	20	20	20	20
Great Basin	14	14	14	14	14	14
Pacific Northwest	37	66	79	48	70	140
Central Pacific	43	58	61	48	77	83
South Pacific	2	2	2	2	2	2
United States	374	537	1, 713	636	799	2, 010

Table 50.—*Annual costs of collection and treatment, by type of program, 1980 and 2000*

[In millions of dollars]

	1980			2000		
	Minimum storage	Minimum costs	Minimum treatment	Minimum storage	Minimum costs	Minimum treatment
New England	162	152	78	305	305	228
Delaware and Hudson	189	167	111	237	237	189
Chesapeake Bay	213	182	118	337	337	263
Southeast	166	79	77	277	190	167
Eastern Great Lakes	156	156	124	331	299	282
Western Great Lakes	254	254	249	431	431	431
Ohio	117	100	100	244	201	201
Cumberland	24	8	7	33	13	12
Tennessee	52	17	16	108	68	50
Upper Mississippi	197	172	118	307	307	246
Lower Mississippi	65	23	23	49	28	21
Upper Missouri	95	95	102	144	144	144
Lower Missouri	21	12	21	36	22	21
Upper Arkansas-White-Red	49	49	44	78	78	78
Lower Arkansas-White-Red	43	18	17	81	33	29
Western Gulf	172	109	109	346	346	346
Upper Rio Grande and Pecos	14	14	14	29	29	29
Colorado	29	29	29	66	66	66
Great Basin	31	31	31	48	48	48
Pacific Northwest	155	54	49	241	131	88
Central Pacific	96	46	44	190	105	102
South Pacific	107	107	107	208	208	208
United States	2, 407	1, 874	1, 591	4, 126	3, 626	3, 249

Table 51.—*Annual total costs of collection, treatment and storage by type of program, 1980, 2000*

[In millions of dollars]

	1980			2000		
	Minimum storage	Minimum costs	Minimum treatment	Minimum storage	Minimum costs	Minimum treatment
New England	169	162	551	323	323	701
Delaware and Hudson	207	187	256	280	280	334
Chesapeake Bay	228	218	379	391	391	524
Southeast	181	119	122	309	263	306
Eastern Great Lakes	173	173	223	374	350	381
Western Great Lakes	311	311	372	525	525	525
Ohio	130	116	116	273	240	240
Cumberland	24	11	12	34	21	25
Tennessee	52	23	31	108	80	132
Upper Mississippi	205	198	303	339	339	431
Lower Mississippi	71	35	35	63	53	63
Upper Missouri	138	138	145	187	187	187
Lower Missouri	23	15	31	41	30	31
Upper Arkansas-White-Red	57	57	67	100	100	100
Lower Arkansas-White-Red	49	34	35	91	63	69
Western Gulf	202	160	160	397	397	397
Upper Rio Grande and Pecos	27	27	27	42	42	42
Colorado	49	49	49	86	86	86
Great Basin	45	45	45	62	62	62
Pacific Northwest	192	120	128	289	201	228
Central Pacific	139	104	105	238	182	185
South Pacific	109	109	109	210	210	210
United States	2, 781	2, 411	3, 301	4, 762	4, 425	5, 259

A comparison of the three alternative programs reveals several relationships that warrant emphasis:

1. The most economical program for 1980 and 2000 apparently is one that emphasizes high level waste treatment, but not the highest attainable;

2. Significant variations in the incidence of cost are implicit in a choice of program. If we assume that waste treatment is primarily a cost of doing business or a cost imposed directly on the household, we can conclude that the incidence of waste treatment costs will be proportional to expenditures for goods and services that contribute to pollution. If we assume that river regulation is largely financed by government, and by the appropriation of money from a general fund, the incidence is largely on the taxpayer. If the country were to adopt a maximum storage, minimum treatment program, in 1980 the costs would be divided as follows:

[In millions]

Maximum storage program, 1980:	
Costs of collection and treatment	$1, 591
Costs of storage	1, 713
Total	3, 301

The division of costs for the opposite program would be:

[In millions]

Minimum storage program, 1980:	
Costs of collection and treatment	$2, 407
Costs of storage	374
Total	2, 781

Based on our assumption with regard to the incidence of costs, these programs can be compared in the following terms:

	Percent of cost borne by—	
	Consumer	Taxpayer
Maximum storage program	48	52
Minimum storage program	87	13

A minimum aggregate cost program for 1980 would appear as follows, if interpreted in the same way:

Percent of cost borne by consumer	78
Percent of cost borne by taxpayer	22

It is recognized that our assumptions regarding incidence are oversimplified; yet they indicate the likelihood that choice of a program will be accompanied by an implicit determination of who shall bear the costs. Specific groups are likely to respond with support or hostility, depending upon the program selected and whether they wish to protect their interests as producers, consumers, or taxpayers;

3. The same combination of treatment and storage meets the objectives of two programs in several regions, apart, of course, from those regions in which water shortage required maximum treatment and maximum flow regardless of program.

The burden of a water resource program: Some comparative measures

None of the programs involves costs that exceed a "reasonable" level. Between 1960 and 1980 GNP at 1960 dollars has been projected to rise from about $520 to $1,060 billion, an increase of $540 billion. Annual storage costs for the program requiring maximum storage would represent four-tenths of 1 percent of the increase; annual treatment costs for the same program would constitute six-tenths of 1 percent of the increase. For the minimum cost program, annual costs for storage and treatment together would constitute only four-tenths of 1 percent of the increase in GNP.

The projected level of storage and treatment costs in 2000 are even a smaller fraction of projected GNP than for 1980. Between 1954 and 2000 it is estimated that GNP will rise from $520 to $2,200 billion. Since the maximum storage program in 2000 is estimated at about $5 billion per year, it is seen that total annual costs of storage and treatment would amount to about three-tenths of 1 percent of the *increase* in GNP.

No accurate estimate of current industrial waste treatment costs is available. It is believed to be in the neighborhood of total municipal waste treatment costs, or about $500 million. Another method of estimating this figure gives approximately the same results. Waste discharge in 1954 was about half the projected medium level for 1980. The degree of waste treatment (BOD removal) is believed to be between 40 percent and 50 percent or about half of the 1980 maximum level of treatment. Since 1980 costs of waste treatment for the minimum storage program were estimated at $2,321 million, this quantity multiplied by ½×½=$600 million.

Current annual costs of low-flow augmentation can only be guessed at. While this has not been a "major purpose" of water resource development,[28] some incidental flow regulation has resulted from navigation, flood control, power, and irrigation programs.

From data prepared for the select committee it was estimated that about 195 million acre-feet of storage capacity had been constructed by the Corps of Engineers and Bureau of Reclamation by 1960. This means that about two-thirds of total reservoir capacity (278 million acre-feet in 1954), had been built by the Federal Government. Since total appropriations for water resource planning, construction, operation, and maintenance had been about $14 billion cumulated to 1954, it would imply that total water resource costs, in 1954, including non-Federal projects, would be about 3/2×$14 billion or $21 billion on the basis of historical prices. Not all of this would have been for storage, however; furthermore, converting to today's prices would raise this figure by a factor of 2 or more. The Bureau of Reclamation [29] estimated that "average cost of total capacity based on median dam" (excluding "powerplants, pumping plants, canal headworks, and other functions not directly required in the storage and release of water"), was $55 per acre-foot at 1959 prices. If we apply this figure to total usable reservoir capacity of 278 million acre-feet, we get $15 billion at 1959 prices invested in storage. If it were *all* used for low-flow regulation—which it is not—the annual cost would be about $15 billion×4.5 percent, or $675 million. It appears, therefore, that present costs of storage and treatment, for the country as a whole, are probably between $500 million (estimated costs of municipal waste treatment) and $1.5 billion (municipal waste treatment plus industrial waste treatment plus storage for low-flow augmentation). We can, therefore, make the following crude comparison:

[Dollars in billions]

	Today	2000
Annual costs of storage and waste treatment	$1.5	$4.4
GNP	$520.0	$2,200.0
Annual water supply costs as percent of GNP	0.3	0.2

Additional required capital facilities—storage, collection, and treatment—are estimated at about $100 billion, to be installed between now and 2000. This represents an average annual outlay of $2½ billion per year. If we accept annual costs of the year 1980 as representative of the average for the period 1960–2000, namely $2.4 billion for the minimum cost program, we see that aggregate annual expenditures including new capital investment for sustained flow and stream quality maintenance would average about $5 billion per year.

Current capital costs of storage and treatment are not known with much accuracy, but it is probable that they have been incurred at a relatively high rate in recent years. The Hoover Commission's Task Force on Water Resources and Power report [30] showed that of total Federal appropriations for water resource development, amounting to $14 billion for the period 1824–1954, about 60 percent, or $9 billion, had been incurred during the period 1941–54. During the period 1951–54, appropriations were at the rate of $1.1 billion per year for capital and current expenditures combined. Since projected capital storage costs will serve part of the same uses for which expenditures are now being incurred, the entire projected annual expenditure for storage is not a net increase over current levels. The minimum cost program involves storage capital costs of about $500 million per year over the period 1960–2000. If 30 percent of total water resource appropriations to the Federal Government are for construction of storage facilities, and if total capital costs have been about $1 billion annually, current Federal expenditures on storage have been about $300 million per year. If Federal expenditures are two-thirds of the total, total capital expenditures on storage would now be about $450 million. It would appear, therefore, that even if we grant a substantial margin of error in our estimates of current storage costs, the magnitudes of today are not remarkably different from those projected for the future.

Capital costs of treatment and collection for the minimum cost program would amount to about $2 billion per year during the next 40 years, divided between municipal and industrial systems. It is likely that the division will be approximately 50–50, although specific conditions will result in local variation in the ratio. At any rate, we see that the general order of magnitude would be about $1 billion per year for cities and towns and about the same expenditure for industrial systems. One billion dollars a year represents about 10 percent of current State and local new public construction at 1959 levels, and about 50 percent of "sewage and water and miscellaneous public service expenditures" in 1959.[31] If State and local capital costs vary proportionately with gross national product, between now and 2000 there will be a fourfold increase. Thus, on the average, capital costs of collection and treatment facilities would be about 5 percent of total capital costs of State and local governments.

---

[28] See list of "major purposes" in table 3, "Report on Water Resources and Power," vol. 1, prepared for Commission on Organization of the Executive Branch of the Government, by the Task Force on Water Resources and Power, 1955.

[29] Material prepared by Arnold Babb, Bureau of Reclamation, unpublished.

[30] Op. cit., 1955, p. 5.

Plant and equipment expenditures for manufacturing facilities have been in the neighborhood of $12 to $15 billion during recent years. If we follow the same reasoning for manufacturing industry as we have for State and local expenditures, we can conclude that waste treatment capital costs will be something on the order of 3 percent of total investment in manufacturing plant and equipment during the period 1960–2000. It is true that by relating treatment capital costs to *all* manufacturing capital outlays, we underestimate the relative burden of such costs to the manufacturing industries directly involved. Pollution is not caused equally by all industries. It so happens, however, that food, pulp and paper, chemicals, and petroleum refining are relatively capital-intensive, and have originated between 43 and 47 percent of total manufacturing expenditures on plant and equipment in recent years. Of capital expenditures made by the four major water-using industries, therefore, outlays for treatment facilities would represent about 6 to 7 percent of total new investment. This result is further mitigated by the fact that projected output of pulp and paper and chemicals increases more rapidly than the average of all manufacturing. Relative to needed capacity for production per se, therefore, the amount needed for waste treatment in these two industries will be below the proportion estimated for the four industries as a whole. Chart 3 shows projected investment in total collection and treatment facilities plus the projected investment in storage capacity for the minimum cost program for the Nation as a whole.

Impact on specific regions

In the course of the discussion so far, only incidental attention has been paid to the water resource problems of a particular region. In this section we shall show that the analysis can be extended to cover certain decisions that are primarily intraregional in scope.

Regionwide hydrologic data can be related to storage costs to reveal prospective changes in the marginal costs of water. For example, consider the following flow-storage relationships in the Rio Grande-Pecos:

> With additional storage of 5,900,000 acre-feet above that presently in place, sustained flow can be raised to 2,100 million gallons per day before, and 940 million gallons per day after reservoir losses.
>
> With additional storage of 7,400,000 acre-feet above that presently in place, sustained flow can be raised to about 2,400 million gallons per day before and 950 million gallons per day after reservoir losses. A still higher quantity of storage adds more to losses than to sustained flow.
>
> Annual costs of 5,900,000 acre-feet of storage are estimated at $8.1 million; costs of 7,400,000 acre-feet are estimated at $12.9 million.
>
> Therefore, to provide a net increase in minimum flow of 10 million gallons per day, annual costs of storage rise by $4.8 million. If 1 million gallons per day costs $480,000 per year, an increase in sustained flow of 1 acre-foot per year costs $429.

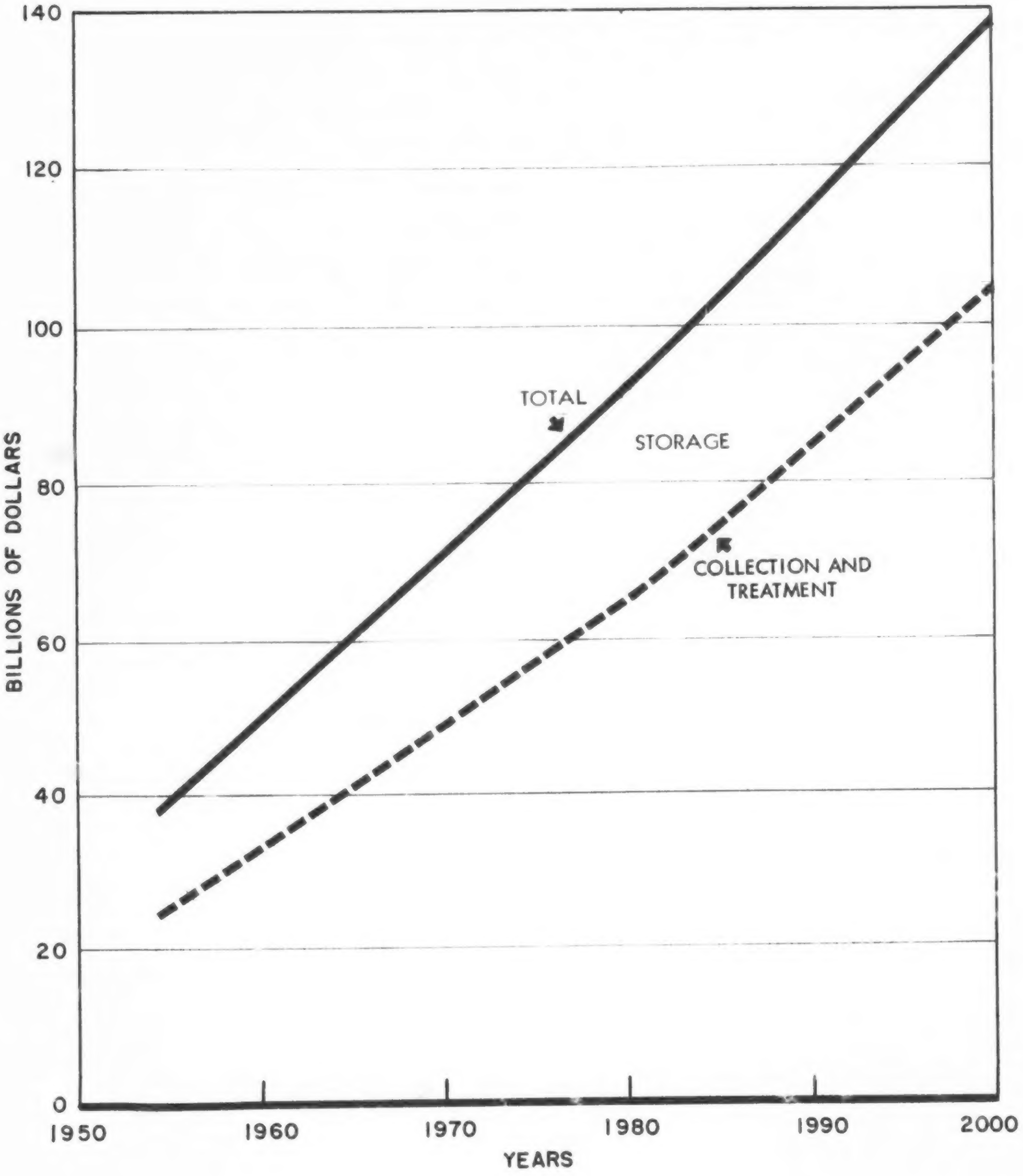
---

[31] Economic Report of the President, January 1960.

CHART 3

INVESTMENT REQUIRED IN COLLECTION, TREATMENT, AND IN STORAGE FACILITIES FOR U.S. TO ACHIEVE DISSOLVED OXYGEN CONTENT OF 4 MG/L

1954 - 2000 MINIMUM COST PROGRAM



A marginal cost of regulated flow equal to $429 per acre-foot seems excessive in terms of today's availability of water, but may well be within a region's tolerance limit by the year 2000. Consider the projected use of water for the Rio Grande-Pecos, year 2000, medium projections, nonagricultural withdrawals only:

[In million gallons per day]

	Withdrawal	Loss
Mining	55	34
Manufacturing	745	68
Thermal power	2,678	150
Municipal	270	54
Total	3,748	306

Losses from municipal and industrial uses alone would be about 300 million gallons per day. Minimum streamflow to maintain water quality (at 97½ percent treatment) are estimated at 3,800 million gallons per day—a flow in excess of average runoff before accounting for losses out of runoff. In other words, projected needs, which are essentially a continuation of trends of the past, far exceed available supplies, without even considering the major depleting uses, agriculture and fish and wildlife swamps and wetlands. The question we have posed, therefore, resolves itself to this: Is it more likely that people and economic activity will in fact locate in other regions in order to avoid high water costs, or that they will pay a marginal flow-regulation cost of about $1.30 per thousand gallons?

If we can anticipate a scientific breakthrough in water use and waste treatment, such that per capita losses and waste dilution requirements are halved—rather sharp, but not inconceivable changes—total requirements for the Rio Grande in the year 2000 would be 150 million gallons per day for losses plus 1,900 million gallons per day for waste dilution. Since this is still twice the maximum flow that can be sustained, we shall assume that all municipal and industrial activities are reduced by 50 percent from projected levels, year 2000. We shall also assume complete recirculation of thermal power cooling water and a gross intake for thermal power equal to loss. Our figures for 2000 would then be, in millions of gallons per day:

	Withdrawal	Loss
Mining	28	17
Manufacturing	370	34
Thermal power	75	75
Municipal	135	27
Total	608	153

It should be noted that in composing this model, agriculture and fish and wildlife habitat have so far been omitted. These two uses will have water only on a "when available" basis, which means that most irrigated agriculture, except at the lower end of the Rio Grande-Pecos, would be abandoned.[32]

Our reconstructed model indicates that gross withdrawals would be roughly of the same magnitude as sustained flows. Since the marginal flow would presumably be "used" only once, marginal storage cost to the user would be the full $1.30 per 1,000 gallons. If technology of water use were to advance further than we have assumed, so that waste dilution flows and losses per unit of intake could be reduced relative to total withdrawals, the cost of storage per unit of gross use would be reduced in proportion to the rate of reuse.

How likely it is that a marginal cost of $1.30 per 1,000 gallons will actually be assumed by residents of the region is, of course, anybody's guess. In the author's opinion it is a most probable result. Average costs of water would be much lower ($13 million for 950 million gallons per day equals $12 per acre-foot), and, since the absolute quantities of both water and money are quite small, marginal costs are likely to be ignored.

In other regions the increase in marginal cost of sustained flow will be much more moderate because increments in net flow will not be so drastically reduced as in the Rio Grande by evaporation from storage. For example, in the Upper Missouri, estimates of marginal yield and marginal cost are as follows:

---

[32] Agriculture at the discharge end of the region can deplete waste-dilution flows which would be available on a sustained basis. Another technical adjustment pertains to the handling of waste. Where full regulation is not feasible, wastes can be impounded and released during periods of natural high flow. This practice would reduce the need for a sustained waste-dilution flow and allow diversion to other purposes. This practice is under study by PHS officials and has also been suggested by Edward J. Cleary of the Ohio River Valley Water Sanitation Commission.

> Additional storage of 28,350,000 acre-feet yields 26,000 million gallons per day after reservoir losses.
>
> Alternatively, additional storage of 30 million acre-feet yields 26,900 million gallons per day after reservoir losses.
>
> Annual costs of storage are $37.8 million for 28,350,000 acre-feet and $43.2 million for 30 million acre-feet.

Hence an increase in annual cost of $5,400,000 yields additional flow of 900 million gallons per day, or $6,000 per million gallons per day, which equals $5.36 per acre-foot.

The Rio Grande and Upper Missouri compare with each other as follows:

	Rio Grande	Upper Missouri
Marginal increment of storage, acre-feet	1,500,000	1,650,000
Increment of net yield, millions of gallons per day	10	900
Increment of storage cost	$4,800,000	$5,400,000
Marginal cost of storage per million gallons per day	$480,000	$6,000
Marginal cost of storage per acre-foot	$429	$5

An analysis such as the foregoing can be used to ascertain what would be involved in a least-cost water resource program for the Nation as a whole, given certain projected national requirements and allowing for redistribution of population and economic activity among regions. The limits of interregional substitution of population and economic activity would first have to be established, keeping national aggregates constant, then within those limits a pattern of national water use could be established that would minimize aggregate storage and treatment costs.

Study of the marginal costs of sustained flow can also be used to throw light on the likelihood that different classes of water users will or will not be able to assume their pro rata share of flow regulation and treatment costs. This question is of special significance in regions in which relatively large quantities of water are currently used for irrigation and in the maintenance of fish and wildlife habitat.

In regions of projected water shortage, depleting uses will not necessarily be eliminated as total water use grows, but may have to be located carefully with reference to reaches of streams in which minimum flows will have to be sustained. In some regions no *reduction* in any uses of water now being made will be necessary, even though projected requirements for 2000, including waste-dilution flows, far exceed maximum available flow. An example of this case is the Upper Missouri. Present withdrawal uses are as follows:

[In million gallons per day]

1954 withdrawal losses:	
Agriculture	13,800
Mining	7
Manufacturing	25
Thermal power	27
Municipal	74
Total	13,970
Estimated municipal and industrial losses, 2000:	
Mining	15
Manufacturing	121
Thermal power	174
Municipal	173
Total	483
Waste-dilution requirements	11,000
Total municipal and industrial required flows	11,483
1954 agricultural losses from runoff	14,000
Total	25,483
Maximum sustained flow, net of reservoir losses	27,000

It will be recalled that marginal costs of full regulation were estimated at $5.30 per acre-foot per year. Since gross withdrawals associated with the above pattern (municipal and industrial uses for year 2000 plus agricultural uses for 1954) would be about 40,000 million gallons per day, the marginal cost of *intake* per acre-foot would not be $5.30 but somewhat less. On the assumption that full marginal storage costs were evenly distributed over all withdrawals, they would amount to $3.58 per acre-foot. An increase over present levels in the cost of water of $3.58 per acre-foot would be a negligible sum for municipal use and well within the capacity of most, if not all, industrial users. For farmers, it would roughly double the present cost of irrigation water, and therefore have a significant effect on total farm costs. We cannot conclude, however, in view of expected changes in agricultural technology, that such an increase would be beyond the farmer's capacity to pay.

In all of this discussion of the Upper Missouri in the year 2000 we have, of course, implicitly assumed that no water would be available for an increase in fish and wildlife habitat. If there is to be such an increase, it is most probable that it would be met out of water otherwise used for irrigation. Hence we would then be faced with the question of whether hunters and fishermen would be able to *expand* their use of water in the next 40 years, or whether irrigation uses would remain constant. (Present supplies of fish and wildlife habitat are already accounted for in runoff. By draining swamps and wetlands and thereby reducing the extent of wildlife habitat, additional water supplies could presumably be made available for agriculture.)

At present, we have neither adequate information nor a generally accepted method of analysis for rendering judgments in cases of this sort. The traditional solution has been found by "leaving it to the market" which, translated, means allowing buyers and sellers of factors of production and buyers and sellers of competing goods and services to work out mutually satisfactory contractual relationships. The result is believed to approximate more closely a condition of maximum aggregate social welfare than any method involving centrally controlled administrative decisions. This faith is probably well placed when it comes to such matters as the "optimum" distribution of ownership between Chevrolets and Fords. The social costs of a Chevrolet and of a Ford are most likely directly proportional to their respective prices; the same is true of the ratio of their respective social benefits. Under these circumstances market behavior is a satisfactory indicator of the way in which aggregate social welfare is maximized; but only insofar as it applies to the choice between a Ford and a Chevrolet.

This same simple condition is not likely to prevail as the categories of goods and services among which comparisons are made are widened. For example, one would probably hesitate to claim that market behavior would adequately reflect the ratios of social benefits and costs between automobiles on the one hand and fallout shelters on the other.

Special circumstances make it unlikely that market behavior adequately reflects the relative aggregate social benefits and costs of certain uses of water. In comparing the market status of fish and wildlife habitat versus agriculture, for example, an adjustment must first be made for the relative impact of Government policies on product and factor prices and on the availability of factors of production. Another adjustment is needed to account for the fact that the bulk of benefits may be enjoyed in one region whereas the costs may be incurred in another. (This is largely true of the habitat services rendered to ducks and geese by the Upper Missouri; much of the fowl ultimately graces the table of a hunter who lives elsewhere. The same statement can be applied to much of the agricultural output of the region.) Finally, it is necessary to account for such factors as the incidence of costs and benefits, latitude given to people in choice of domicile, and maximization of regional vis-a-vis national income. By the time a judgment has been rendered on water use a number of important decisions regarding the economy as a whole will have been made.

PART IV. REGIONAL WATER SUPPLY AND PROJECTED USES

(Prepared by Vera F. Eliasberg)

In this part are set forth tables and charts that summarize flow/storage relationships and projections of water use for each region. In addition, charts 5, 6, and 7 show the variations to be found among regions with respect to relative rates of population increase, the ratio of losses to dilution requirements, and relative surplus or deficit in water supply.

Tables 52-A—52-W show, for each region, estimates of withdrawals, losses from withdrawal and onsite uses, flow requirements for 1954, 1980, and 2000, and maximum sustained flow after adjustment for additional reservoir losses. Flows shown for "waste dilution" are total streamflow requirements on the basis of the level of treatment associated with the minimum *cost* program.

In charts 4-A to 4-V, flow/storage relationships, projected losses from all uses, and total required streamflow to provide adequate waste dilution for 1980 and 2000 are given for each region. (All measurements are, of course, for medium projections of population and economic growth and for streamflows to provide a dissolved oxygen content of 4 milligrams per liter.) For most regions the flow/storage curve is computed without regard for losses from added storage, but in several regions where the differences are critical curves are also shown for flows after adjustment for reservoir losses. In some regions, where maximum conceivable water requirements fell substantially below maximum potential supply, only a segment of the flow/storage curve was drawn. Total streamflows for waste dilution are for the minimum cost program.

Chart 6 and table 53-A can be compared. It will be seen that relatively high losses are characteristic of regions in which irrigation and wildlife propagation are comparatively large water users.

Tables 54-A and 54-B show for each region the ratio of the maximum obtainable supply to the flow requirement, based on losses and waste dilution flows of the minimum storage program. These ratios are graphically depicted in chart 7.

A comparison of charts 5 and 7 shows that a direct correlation exists between anticipated relative changes in population and anticipated intensity of water shortage.

CHART 4–A

NEW ENGLAND REGION

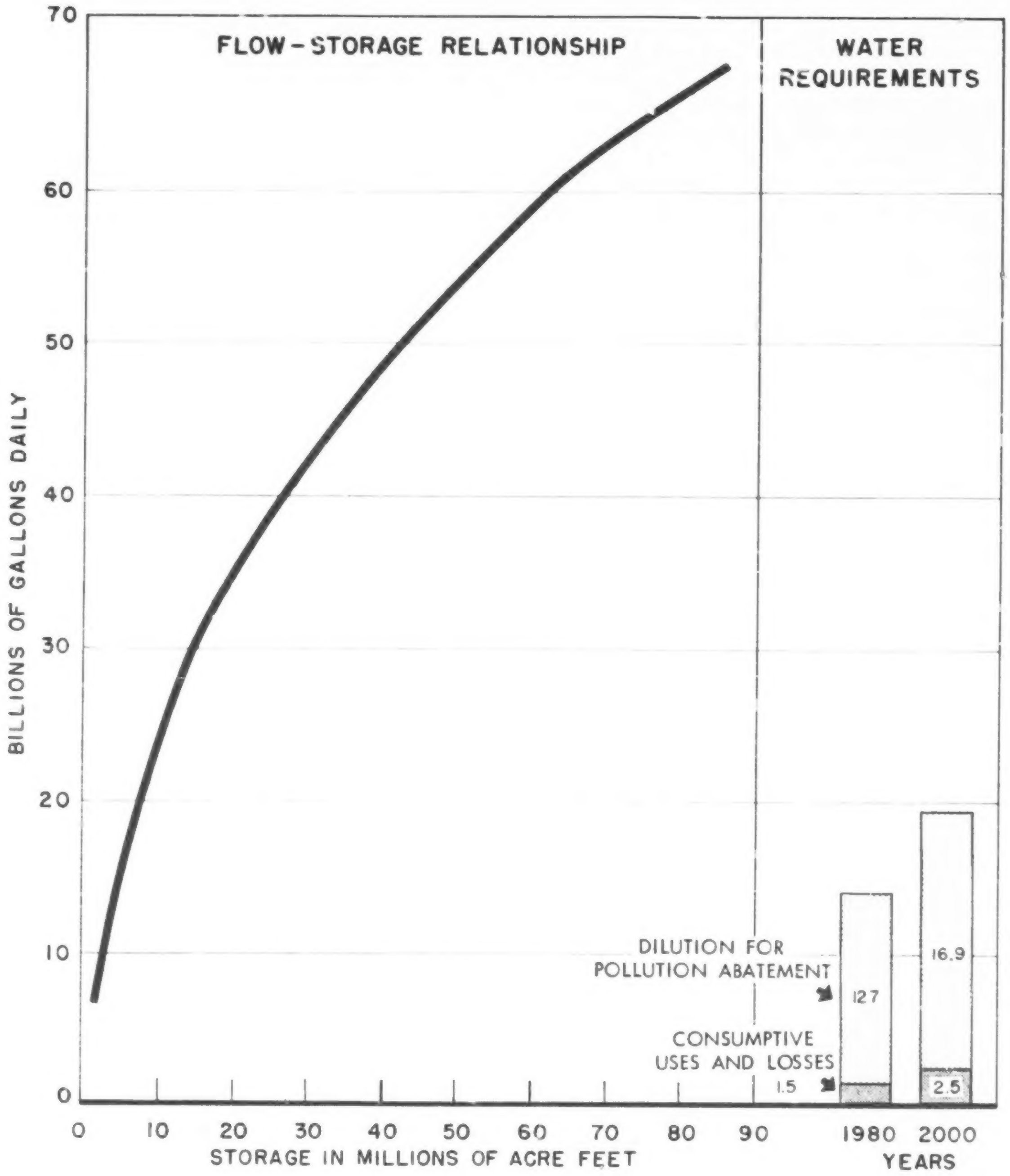


TABLE 52-A.—*Summary: Withdrawals, losses, and flows, New England region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	0.1	0.3	0.5
Mining	(1)	(1)	(1)
Manufacturing	1.6	4.6	10.0
Steam-electric power	3.6	11.6	18.7
Municipal	1.0	1.5	2.0
Total	6.3	18.0	31.2
Losses:			
Withdrawal uses:			
Agriculture	.1	.1	.3
Mining	(1)	(1)	(1)
Manufacturing	.2	.5	1.1
Steam-electric power	(1)	(1)	(1)
Municipal	.1	.1	.2
Total	.4	.7	1.6
Onsite uses[2]			
Land treatment and structures	(.3)	.4	.5
Swamps and wetlands[3]	(.4)	.3	.4
Total	(.7)	.7	.9
Total losses from runoff[2]	.4	1.5	2.5
Flows:			
Hydroelectric power	29.5	26.8	26.8
Sport fish habitat	6.2	10.3	12.9
Waste dilution[4] [5]	48.5	12.7	16.9
Total losses plus waste dilution flows	48.9	14.2	19.4
Maximum low flow that can be sustained[6]			64.7

---

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses. "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

Chart 4-B

DELAWARE AND HUDSON RIVERS REGION

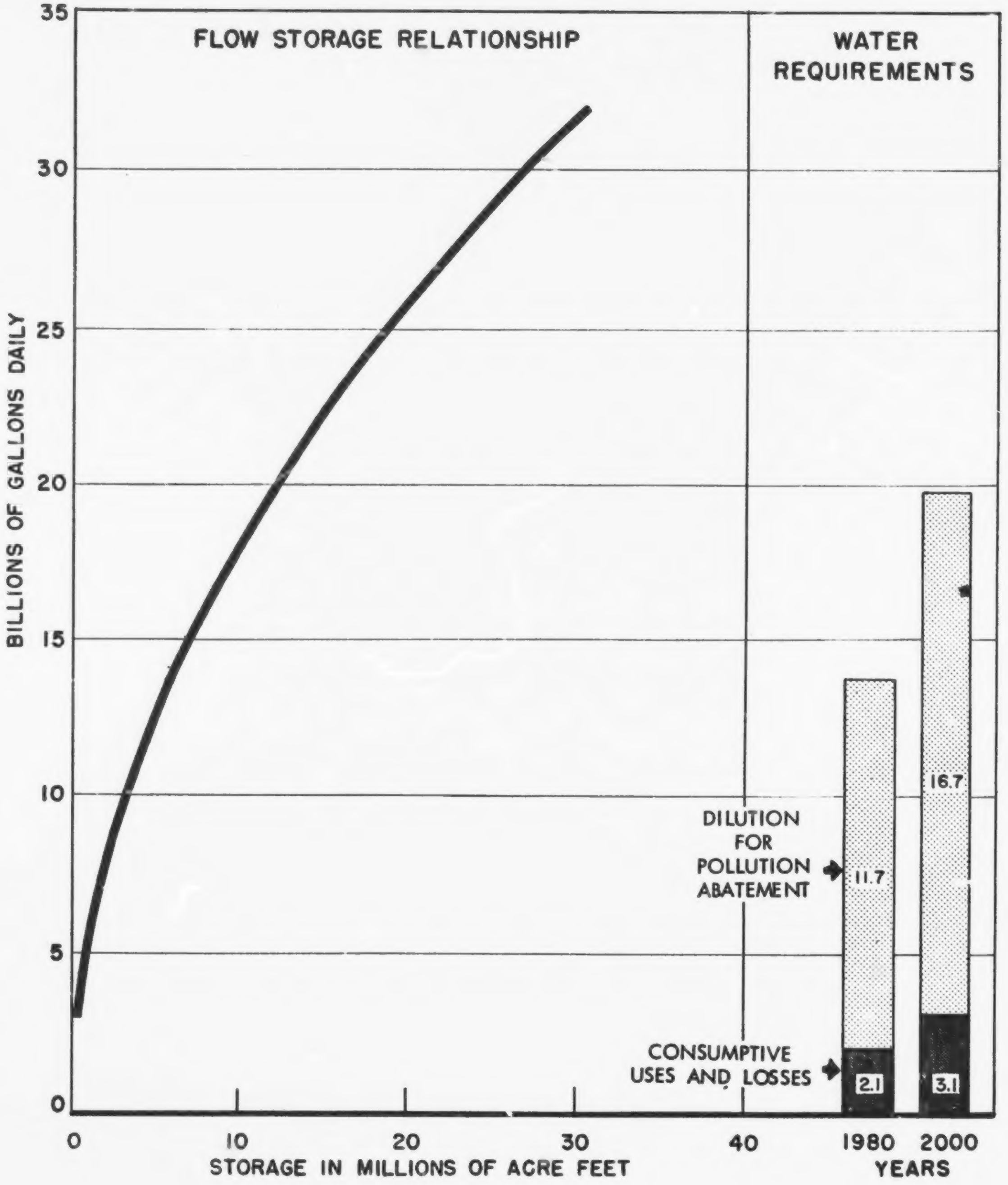


TABLE 52-B.—*Summary: Withdrawals, losses, and flows, Delaware and Hudson region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	0.3	0.4	0.6
Mining	.1	.1	.1
Manufacturing	3.1	8.3	17.0
Steam-electric power	8.9	23.2	35.7
Municipal	2.4	3.8	5.3
Total	14.8	35.8	58.7
Losses:			
Withdrawal uses:			
Agriculture	.2	.3	.5
Mining	(1)	(1)	(1)
Manufacturing	.2	.4	.9
Steam-electric power	(1)	(1)	.1
Municipal	.4	.4	.5
Total	.8	1.1	2.0
Onsite uses: [2]			
Land treatment and structures	(−.1)	−.1	−.2
Swamps and wetlands [3]	(1.3)	1.0	1.3
Total	(1.2)	.9	1.1
Total losses from runoff [2]	.8	2.1	3.1
Flows:			
Hydroelectric power	8.9	9.8	9.8
Sport fish habitat	8.0	17.5	23.4
Waste dilution [4] [5]	24.3	11.7	16.7
Total losses plus waste dilution flows	25.1	13.8	19.8
Maximum low flow that can be sustained [6]			31.1

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

Chart 4–C

CHESAPEAKE BAY REGION

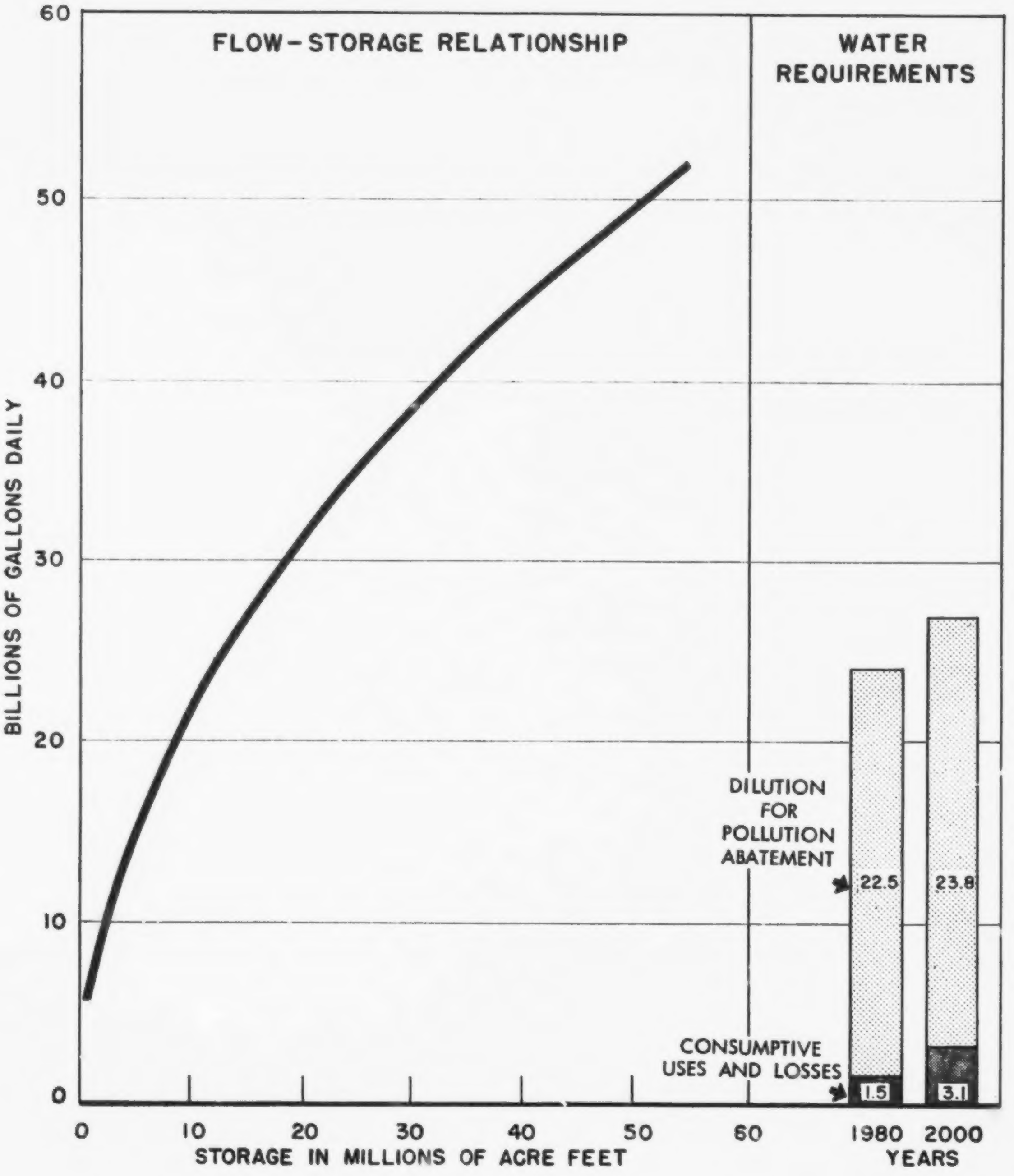


TABLE 52-C.—*Summary: Withdrawals, losses, and flows, Chesapecke Bay region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	0.2	0.4	1.5
Mining	.1	.1	.1
Manufacturing	1.6	5.5	11.7
Steam-electric power	4.5	13.4	20.5
Municipal	.8	1.4	2.2
Total	7.2	20.8	36.0
Losses:			
Withdrawal uses:			
Agriculture	.1	.2	1.2
Mining	(1)	(1)	(1)
Manufacturing	.1	.3	.6
Steam-electric power	----	(1)	(1)
Municipal	.1	.1	.2
Total	.3	.6	2.0
Onsite uses:[2]			
Land treatment and structures	(1)	.1	.1
Swamps and wetlands[3]	(.9)	.7	.9
Total	(.9)	.8	1.0
Total losses from runoff[2]	.3	1.5	3.1
Flows:			
Hydroelectric power	20.5	24.1	31.2
Sport fish habitat	9.8	23.2	33.0
Waste dilution[4 5]	31.8	22.5	23.8
Total losses plus waste dilution flows	32.1	24.0	26.9
Maximum low flow that can be sustained[6]			50.8

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

Chart 4–D

SOUTHEAST REGION

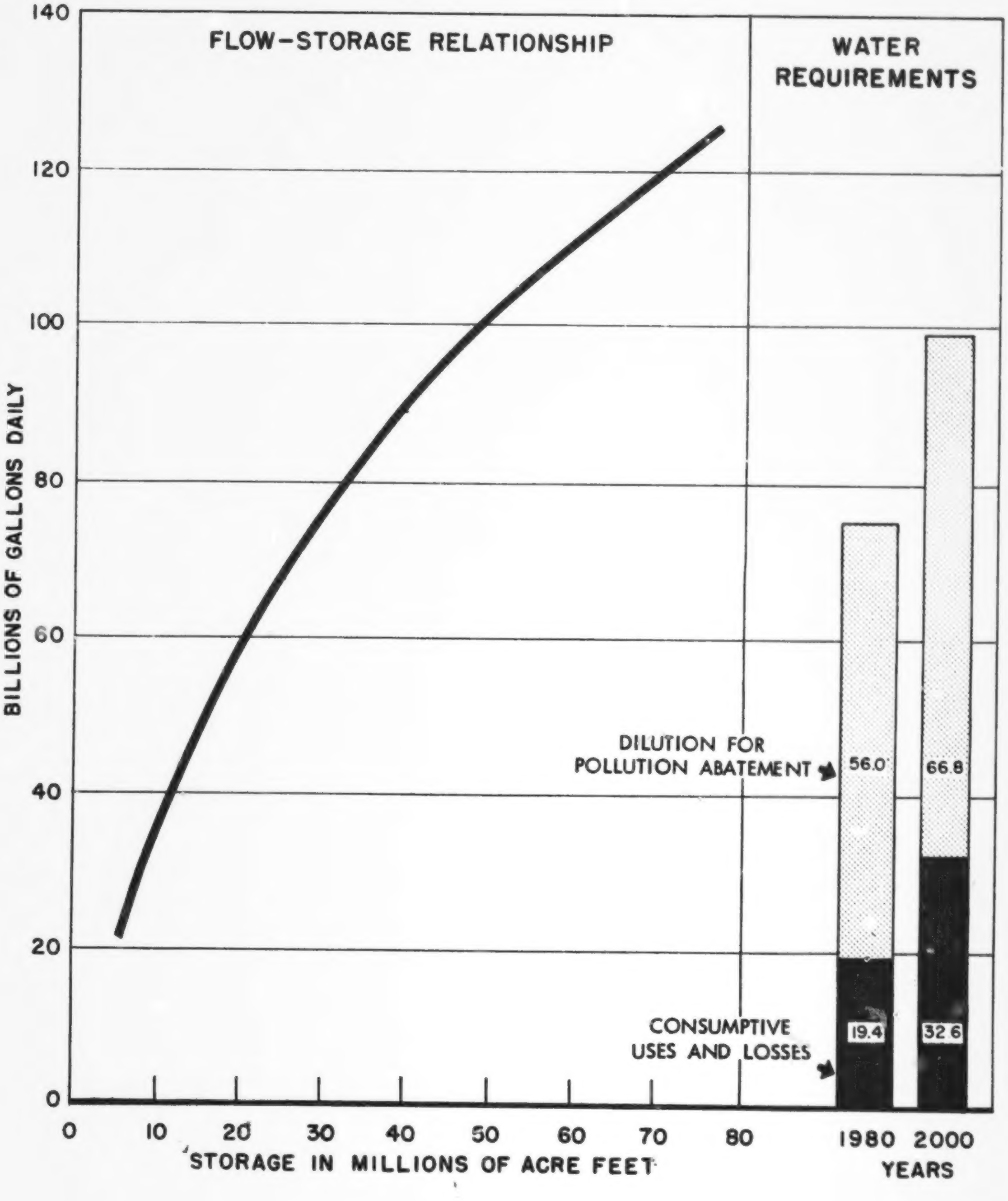


Table 52-D.—*Summary: Withdrawals, losses, and flows, Southeast region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	1.7	3.3	9.7
Mining	.2	.1	.1
Manufacturing	2.1	8.1	19.5
Steam-electric power	6.2	25.9	41.1
Municipal	1.0	1.8	2.8
Total	11.2	39.2	73.2
Losses:			
Withdrawal uses:			
Agriculture	1.4	2.4	8.1
Mining	(1)	(1)	(1)
Manufacturing	.4	1.4	3.4
Steam-electric power	(1)	(1)	(1)
Municipal	.1	.2	.3
Total	1.9	4.0	11.8
Onsite uses: [2]			
Land treatment and structures	(.4)	.5	.9
Swamps and wetlands [3]	(19.9)	14.9	19.9
Total	(20.3)	15.4	20.8
Total losses from runoff [2]	1.9	19.4	32.6
Flows:			
Hydroelectric power	30.4	59.8	67.0
Navigation	12.2	19.9	19.9
Sport fish habitat	2.7	9.8	13.9
Waste dilution [4] [5]	25.5	56.0	66.8
Total losses plus waste dilution flows	27.4	75.4	99.4
Maximum low flow that can be sustained [6]			207.4

---

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

CHART 4–E

EASTERN GREAT LAKES REGION

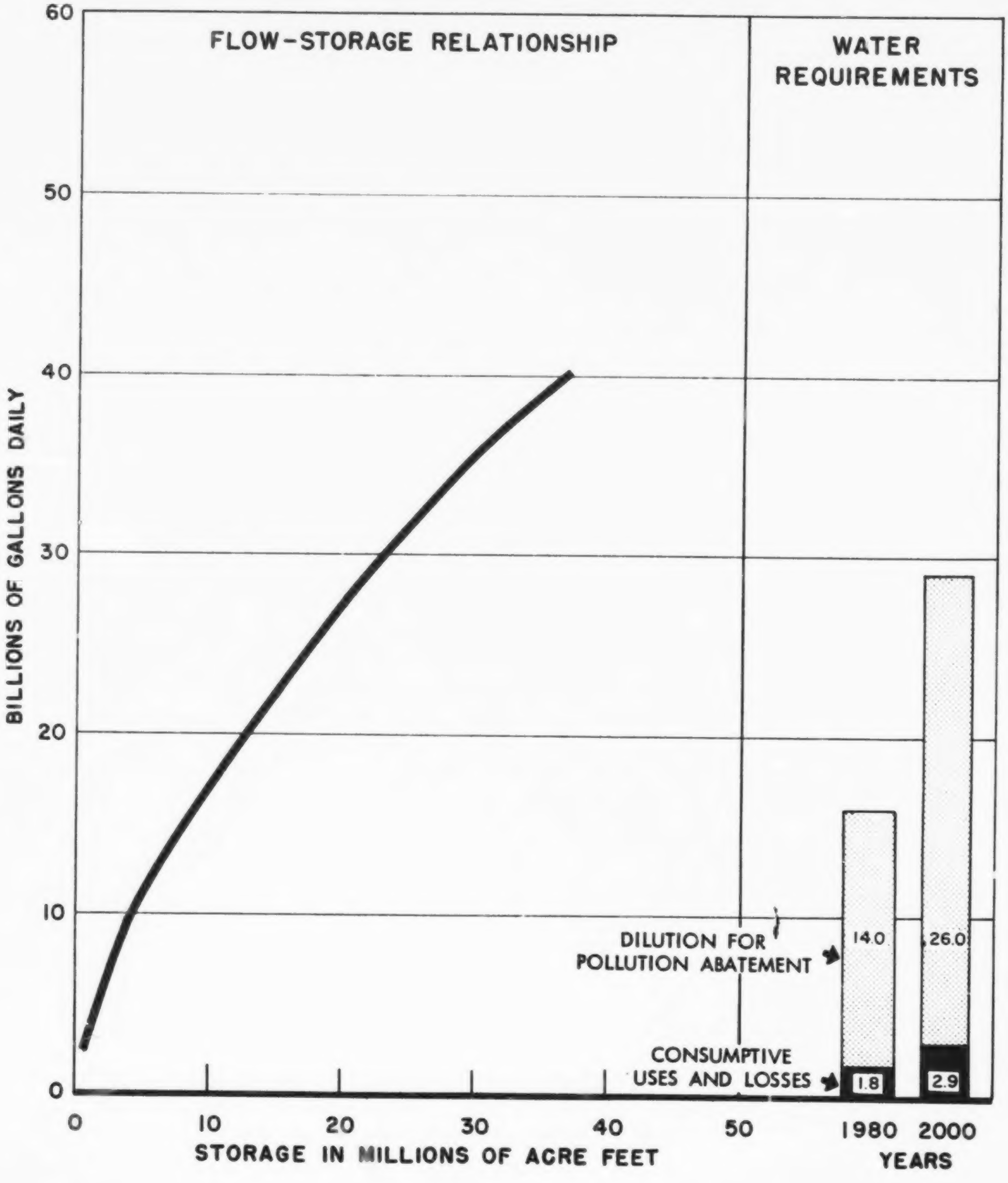


Table 52-E.—*Summary: Withdrawals, losses, and flows, Eastern Great Lakes region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	0.1	0.3	0.8
Mining	(1)	.2	.3
Manufacturing	4.0	12.2	25.4
Steam-electric power	5.4	17.0	27.7
Municipal	1.7	2.8	4.1
Total	11.2	32.5	58.3
Losses:			
Withdrawal uses:			
Agriculture	.1	.1	.6
Mining	(1)	(1)	(1)
Manufacturing	.1	.4	.8
Steam-electric power	(1)	(1)	(1)
Municipal	.2	.3	.4
Total	.4	.8	1.8
Onsite uses:[2]			
Land treatment and structures	(.1)	.1	
Swamps and wetlands[3]	(1.1)	.8	1.1
Total	(1.2)	.9	1.1
Total losses from runoff[2]	.4	1.8	2.9
Flows:			
Hydroelectric power	46.4	101.8	101.8
Navigation	1.3	1.6	1.6
Sport fish habitat	9.6	20.1	28.0
Waste dilution[4] [5]	49.4	14.0	26.0
Total losses plus waste dilution flows	49.8	15.8	28.9
Maximum low flow that can be sustained[6]			**38.6**

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

CHART 4-F

WESTERN GREAT LAKES REGION

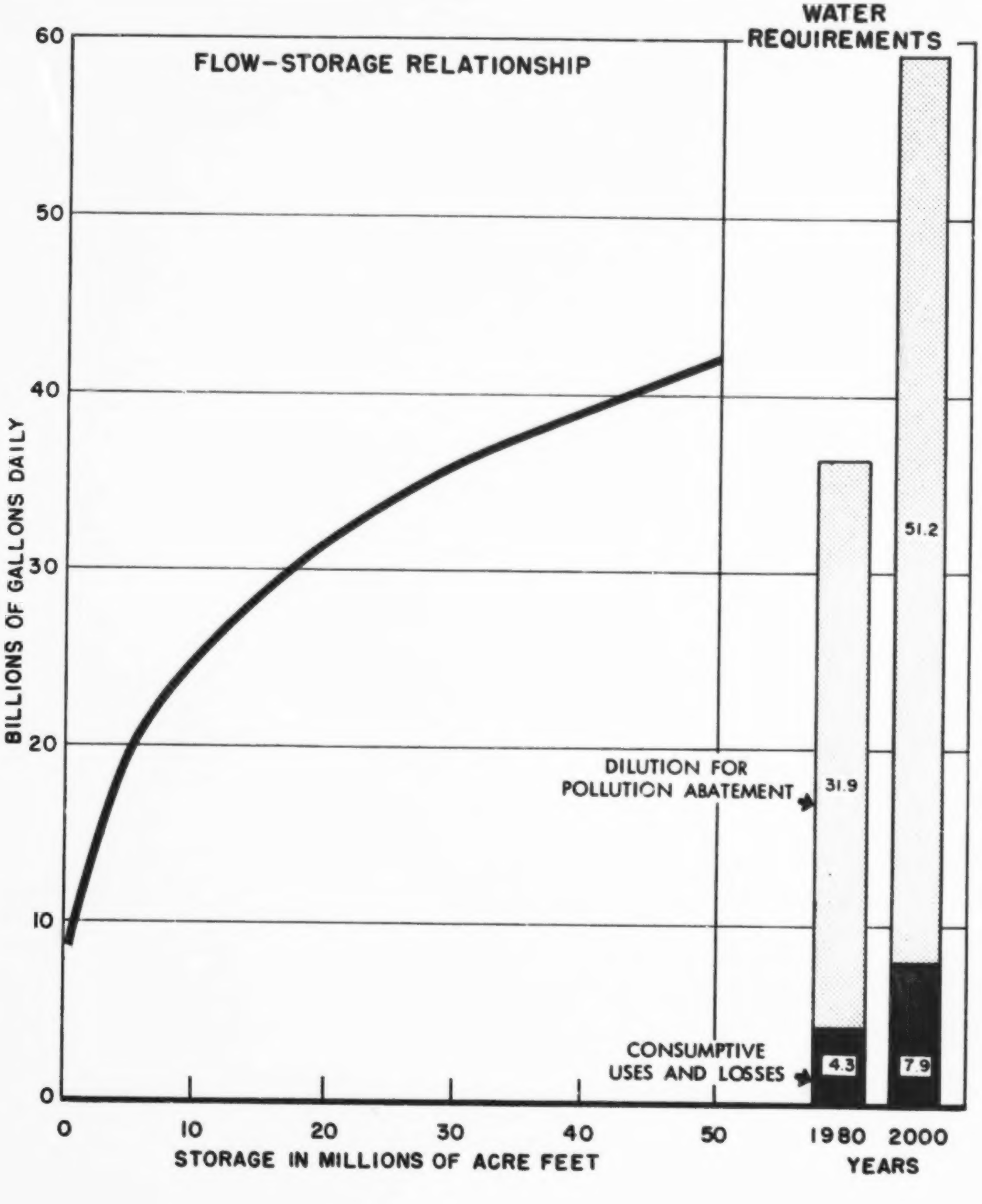


TABLE 52-F.—*Summary: Withdrawals, losses, and flows, Western Great Lakes region*

[Billions of gallons per day]

	1954	1960	2000
Withdrawals:			
Agriculture	0.2	0.6	1.5
Mining	.1	.1	.1
Manufacturing	4.3	11.6	23.5
Steam-electric power	6.2	22.3	35.7
Municipal	2.1	3.4	4.6
Total	12.9	38.0	65.4
Losses:			
Withdrawal uses:			
Agriculture	.2	.3	1.2
Mining	(1)	(1)	(1)
Manufacturing	.2	.8	2.5
Steam-electric power	(1)	(1)	(1)
Municipal	.2	.3	.5
Total	.6	1.4	4.2
Onsite uses: [2]			
Land treatment and structures	(.1)	.1	.1
Swamps and wetlands [3]	(3.6)	2.7	3.6
Total	(3.7)	2.8	3.7
Total losses from runoff [3]	.6	4.3	7.9
Flows:			
Hydroelectric power	33.0	35.7	35.7
Sport fish habitat	10.0	19.2	27.7
Waste dilution [4] [5]	128.5	31.9	51.2
Total losses plus waste dilution flows	129.1	36.2	59.1
Maximum low flow that can be sustained [6]			40.0

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

CHART 4-G

OHIO RIVER REGION

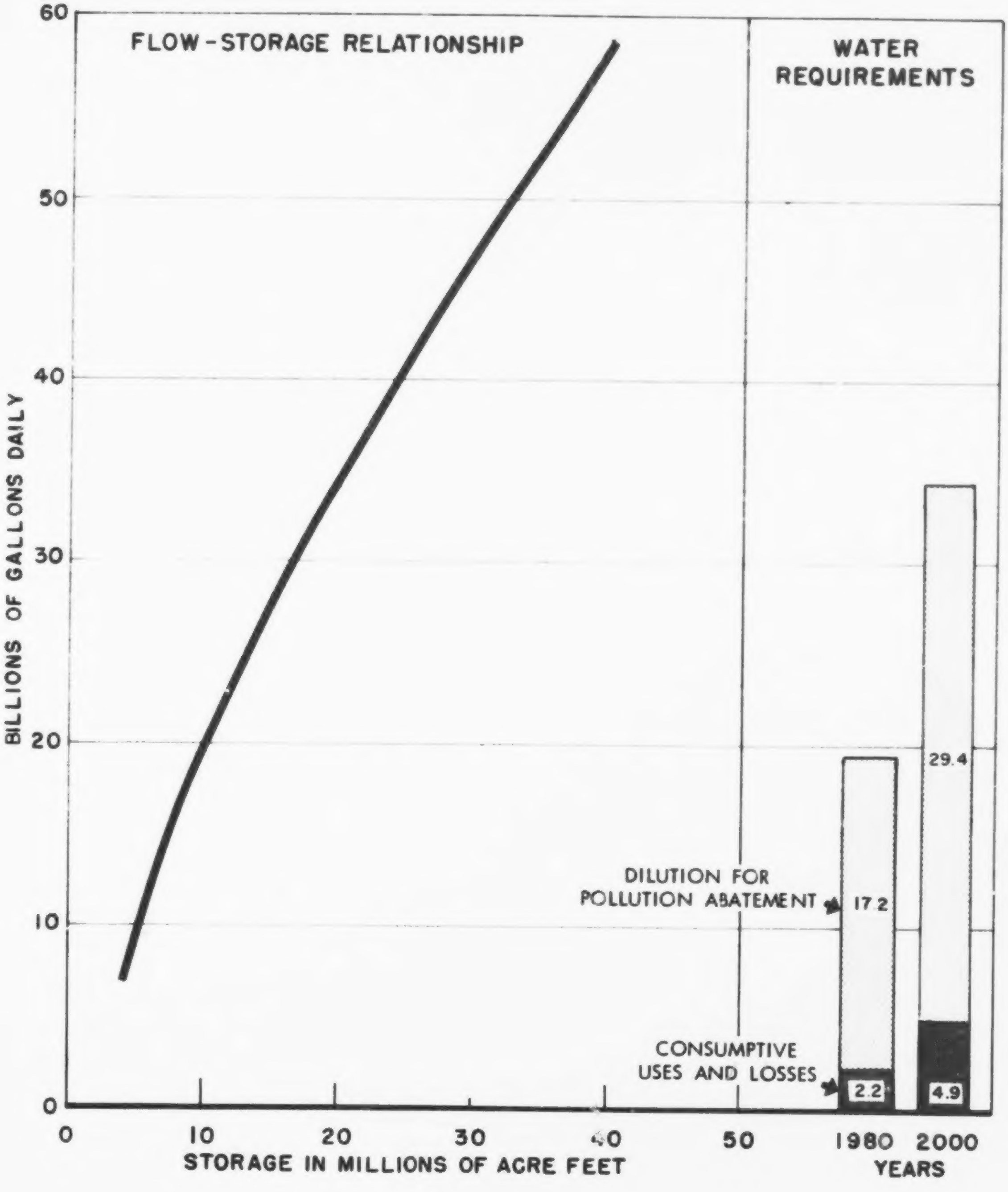


TABLE 52-G.—*Summary: Withdrawals, losses, and flows, Ohio region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	0.3	0.9	2.4
Mining	.2	.3	.4
Manufacturing	5.8	15.4	29.4
Steam-electric power	14.3	48.2	75.0
Municipal	1.4	2.4	3.5
Total	22.0	67.2	110.7
Losses:			
Withdrawal uses:			
Agriculture	.2	.4	1.8
Mining	.1	.1	.1
Manufacturing	.3	.9	1.8
Steam-electric power	(1)	.1	.2
Municipal	.1	.2	.3
Total	.7	1.7	4.2
Onsite uses:[2]			
Land treatment and structures	(.2)	.4	.5
Swamps and wetlands[3]	(.2)	.1	.2
Total	(.4)	.5	.7
Total losses from runoff[2]	.7	2.2	4.9
Flows:			
Hydroelectric power	17.0	35.7	35.7
Navigation	.6	1.2	1.5
Sport fish habitat	4.0	7.1	9.8
Waste dilution[4] [5]	9.5	17.2	29.4
Total losses plus waste dilution flows	10.2	19.4	34.3
Maximum low flow that can be sustained[6]			108.5

---

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

Chart 4-H

CUMBERLAND RIVER REGION

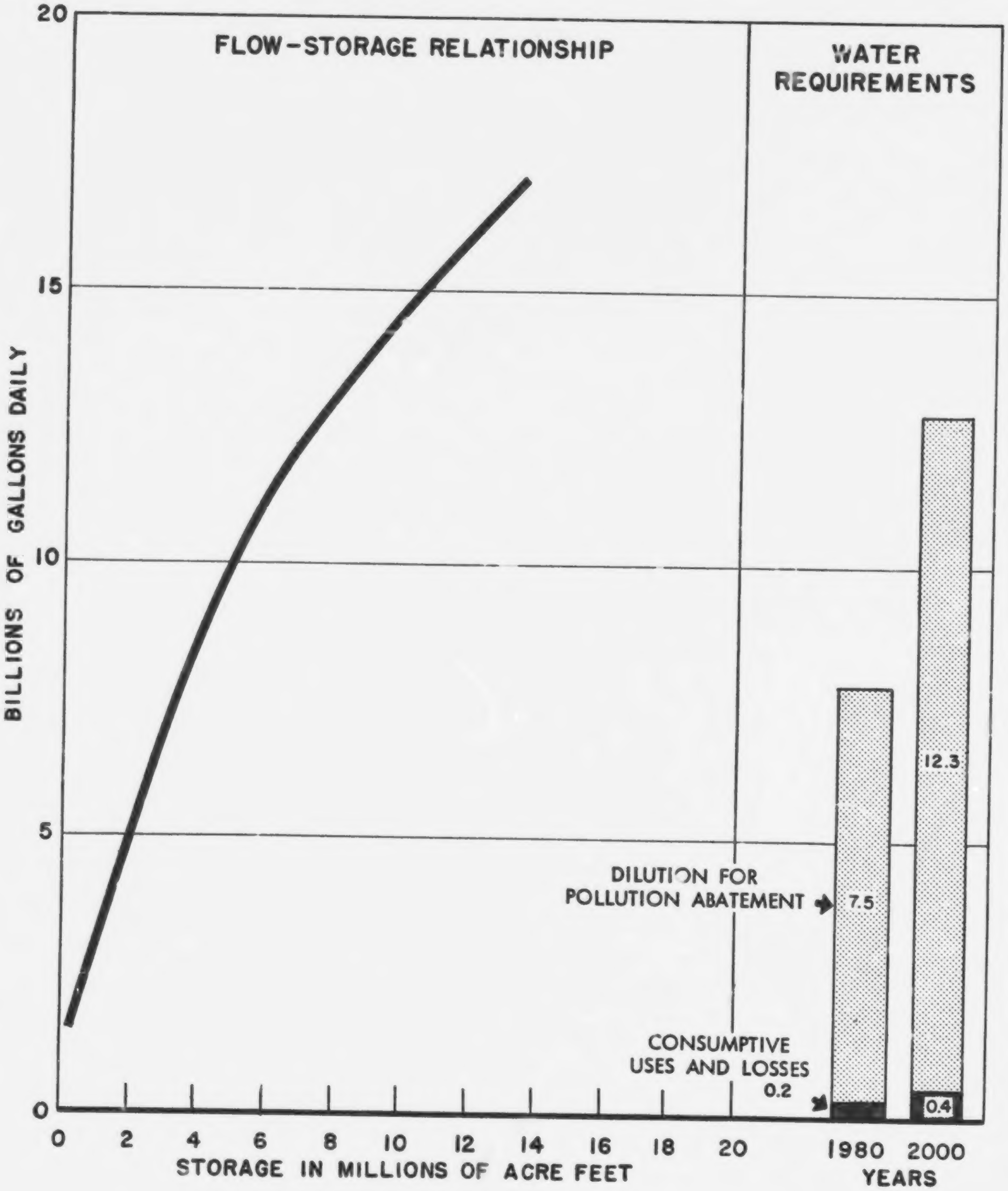


TABLE 52-H.—*Summary: Withdrawals, losses, and flows, Cumberland region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	(1)	0.1	0.2
Mining	(1)	(1)	(1)
Manufacturing	(1)	.3	.7
Steam-electric power	--------	--------	.9
Municipal	0.1	.1	.2
Total	.1	.5	2.0
Losses:			
Withdrawal uses:			
Agriculture	(1)	(1)	.1
Mining	(1)	(1)	(1)
Manufacturing	--------	(1)	(1)
Steam-electric power	--------	--------	.1
Municipal	(1)	(1)	(1)
Total	(1)	(1)	.2
Onsite uses: [2]			
Land treatment and structures	(.1)	.1	.1
Swamps and wetlands [3]	(1)	(1)	(1)
Total	(.1)	.1	.1
Total losses from runoff [2]	(1)	.2	.4
Flows:			
Hydroelectric power	5.4	13.4	13.4
Navigation	.1	.1	.2
Sport fish habitat	.5	.9	1.1
Waste dilution [4] [5]	3.1	7.5	12.3
Total losses plus waste dilution flows	3.1	7.7	12.7
Maximum low flow that can be sustained [6]			15.5

---

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

Chart 4–I

TENNESSEE RIVER REGION

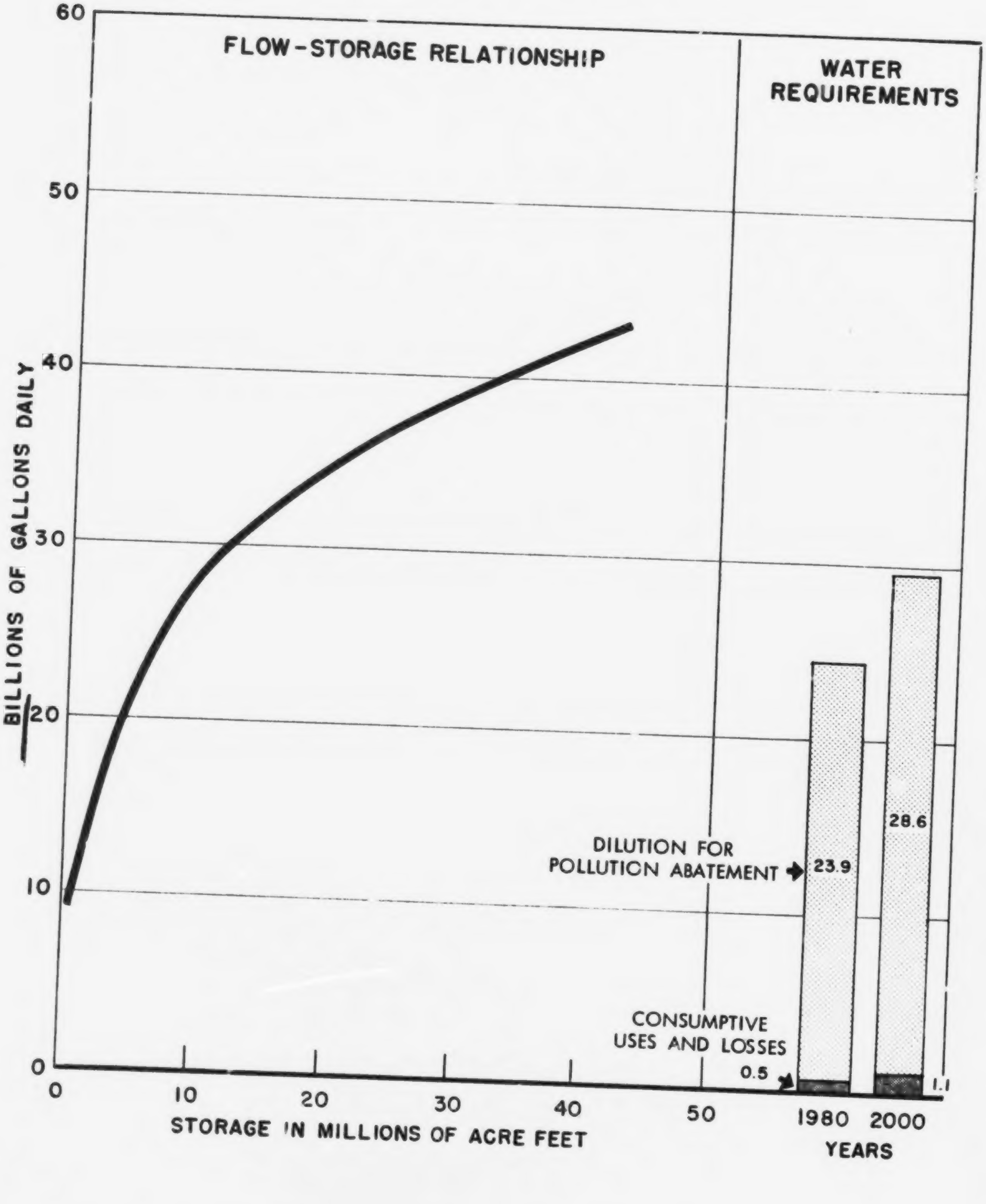


TABLE 52-I.—*Summary: Withdrawals, losses, and flows, Tennessee region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	0.1	0.2	0.4
Mining	(1)	(1)	(1)
Manufacturing	.6	2.3	5.6
Steam-electric power	2.7	8.9	17.9
Municipal	.2	.3	.4
Total	3.6	11.7	24.3
Losses:			
Withdrawal uses:			
Agriculture	.1	.1	.3
Mining	(1)	(1)	(1)
Manufacturing	(1)	.2	.4
Steam-electric power	...	(1)	(1)
Municipal	(1)	(1)	(1)
Total	.1	.3	.7
Onsite uses: [2]			
Land treatment and structures	(.1)	.1	.3
Swamps and wetlands [3]	(.1)	(1)	.1
Total	(.2)	.1	.4
Total losses from runoff [2]	.1	.5	1.1
Flows:			
Hydroelectric power	24.1	33.9	33.9
Navigation	...	.8	.8
Sport fish habitat	1.2	2.6	3.1
Waste dilution [4] [5]	12.5	23.9	28.6
Total losses plus waste dilution flows	12.6	24.4	29.7
Maximum low flow that can be sustained [6]			42.6

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

Chart 4–J

UPPER MISSISSIPPI RIVER REGION

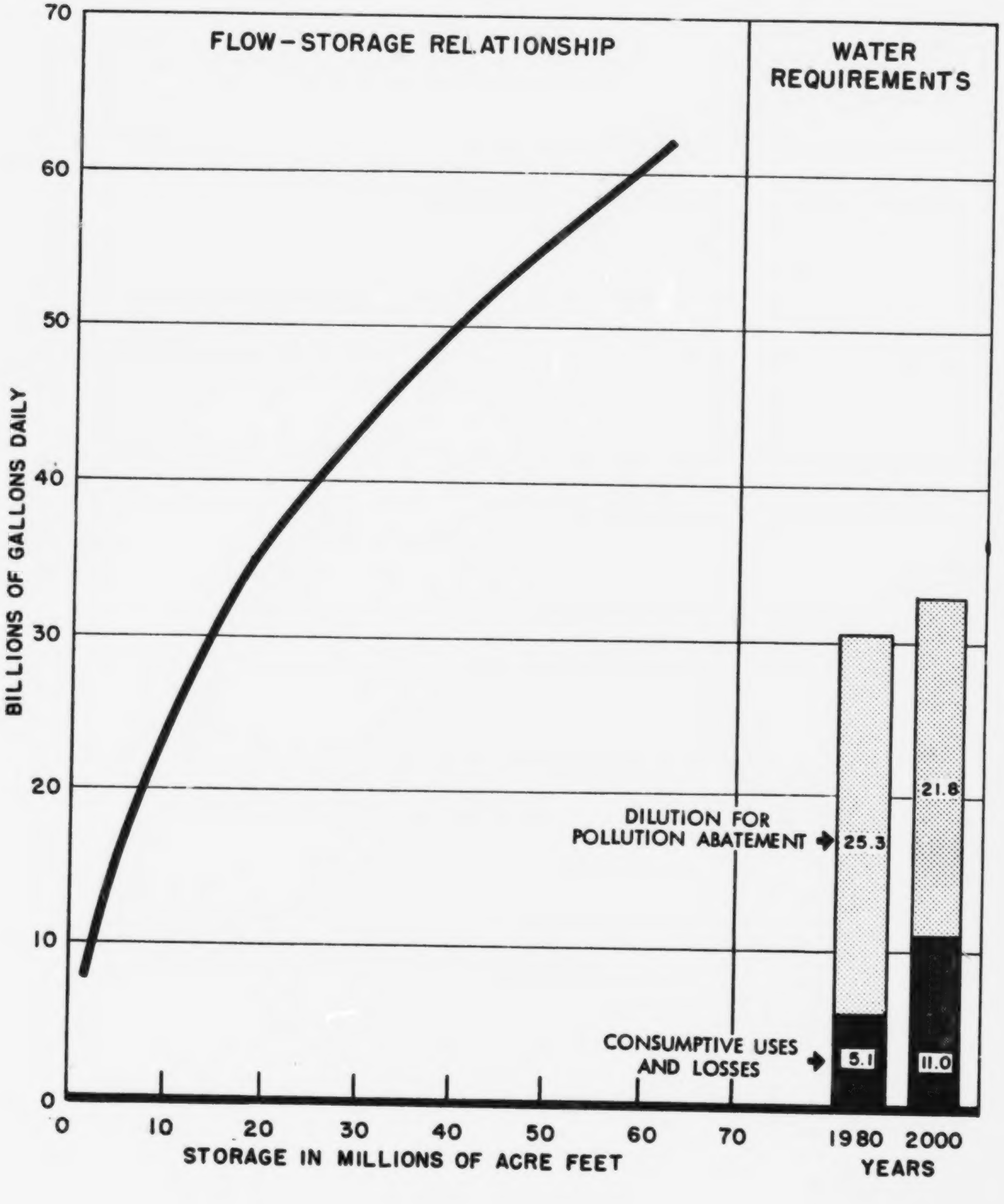


TABLE 52-J.—*Summary: Withdrawals, losses, and flows, Upper Mississippi region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	0.4	0.9	5.4
Mining	.1	.2	.3
Manufacturing	1.5	3.5	6.8
Steam-electric power	5.4	16.1	25.0
Municipal	1.1	1.8	2.5
Total	8.5	22.5	40.0
Losses:			
Withdrawal uses:			
Agriculture	.3	.6	4.6
Mining	(1)	(1)	(1)
Manufacturing	.1	.3	.6
Steam-electric power	(1)	(1)	(1)
Municipal	.1	.2	.3
Total	.5	1.1	5.6
Onsite uses: [2]			
Land treatment and structures	(.2)	.3	.6
Swamps and wetlands: [3]	(4.9)	3.6	4.9
Total	(5.1)	3.9	5.5
Total losses from runoff [2]	.5	5.1	11.0
Flows:			
Hydroelectric power	32.1	29.5	32.1
Navigation	45.2	48.5	48.5
Sport fish habitat	4.5	8.9	11.1
Waste dilution [4, 5]	58.4	25.3	21.8
Total losses plus waste dilution flows	58.9	30.4	32.8

Maximum low flow that can be sustained [6] 58.9

---

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

Chart 4-K

LOWER MISSISSIPPI RIVER REGION

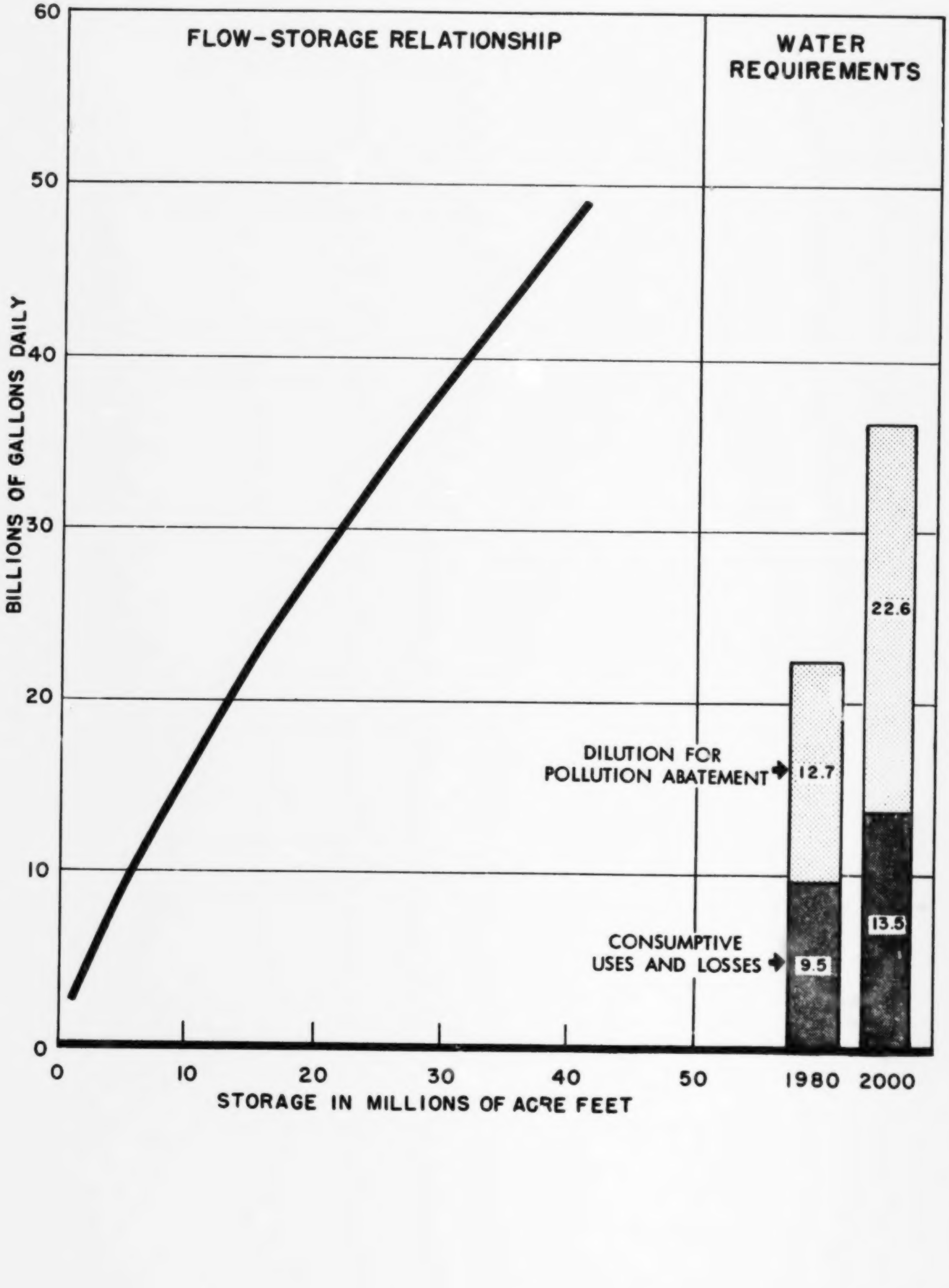


TABLE 52-K.—*Summary: Withdrawals, losses, and flows, Lower Mississippi region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	1.4	2.1	3.5
Mining	.1	.2	.2
Manufacturing	.9	2.4	6.4
Steam-electric power	1.8	3.6	5.4
Municipal	.2	.4	.5
Total	4.4	8.7	16.0
Losses:			
Withdrawal uses:			
Agriculture	1.2	1.9	3.1
Mining	([1])	([1])	([1])
Manufacturing	([1])	.1	.2
Steam-electric power	.1	.2	.3
Municipal	([1])	([1])	.1
Total	1.3	2.2	3.7
Onsite uses:[2]			
Land treatment and structures	(.2)	.2	.3
Swamps and wetlands [3]	(9.5)	7.1	9.5
Total	(9.7)	7.3	9.8
Total losses from runoff [2]	1.3	9.5	13.5
Flows:			
Navigation	90.5	97.1	97.1
Sport fish habitat	1.0	2.2	2.5
Waste dilution [4] [5]	5.2	12.7	22.6
Total losses plus waste dilution flows	6.5	22.2	36.1

Maximum low flow that can be sustained [6] 47.5

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

CHART 4–L

UPPER MISSOURI RIVER REGION

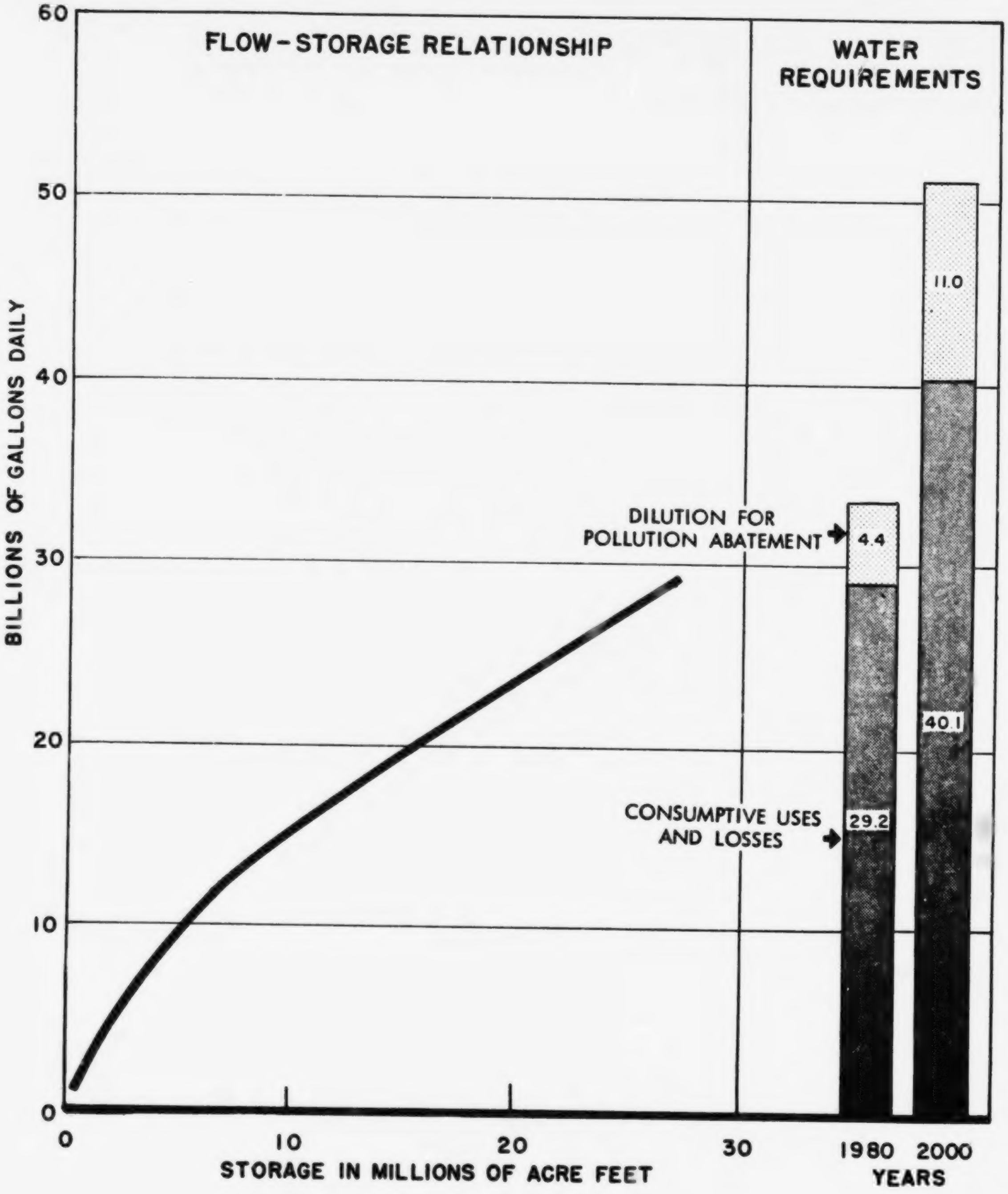


TABLE 52-L.—*Summary: Withdrawals, losses, and flows, Upper Missouri region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	25.4	25.4	32.5
Mining	.1	.1	.1
Manufacturing	.3	.7	2.2
Steam-electric power	1.8	7.1	11.6
Municipal	.4	.6	.9
Total	28.0	33.9	47.3
Losses:			
Withdrawal uses:			
Agriculture	13.8	15.0	20.5
Mining	(1)	(1)	(1)
Manufacturing	(1)	.1	.1
Steam-electric power	(1)	.1	.2
Municipal	.1	.1	.2
Total	13.9	15.3	21.0
Onsite uses: [2]			
Land treatment and structures	(1.0)	.7	1.5
Swamps and wetlands [3]	(17.7)	13.1	17.6
Total	(18.7)	13.8	19.1
Total losses from runoff [2]	13.9	29.2	40.1
Flows:			
Hydroelectric power	4.5	23.2	25.0
Sport fish habitat	4.3	7.6	9.4
Waste dilution [4] [5]	19.1	4.4	11.0
Total losses plus waste dilution flows	33.0	33.6	51.1

Maximum low flow that can be sustained [6] 26.9

---

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

Chart 4-M

LOWER MISSOURI RIVER REGION

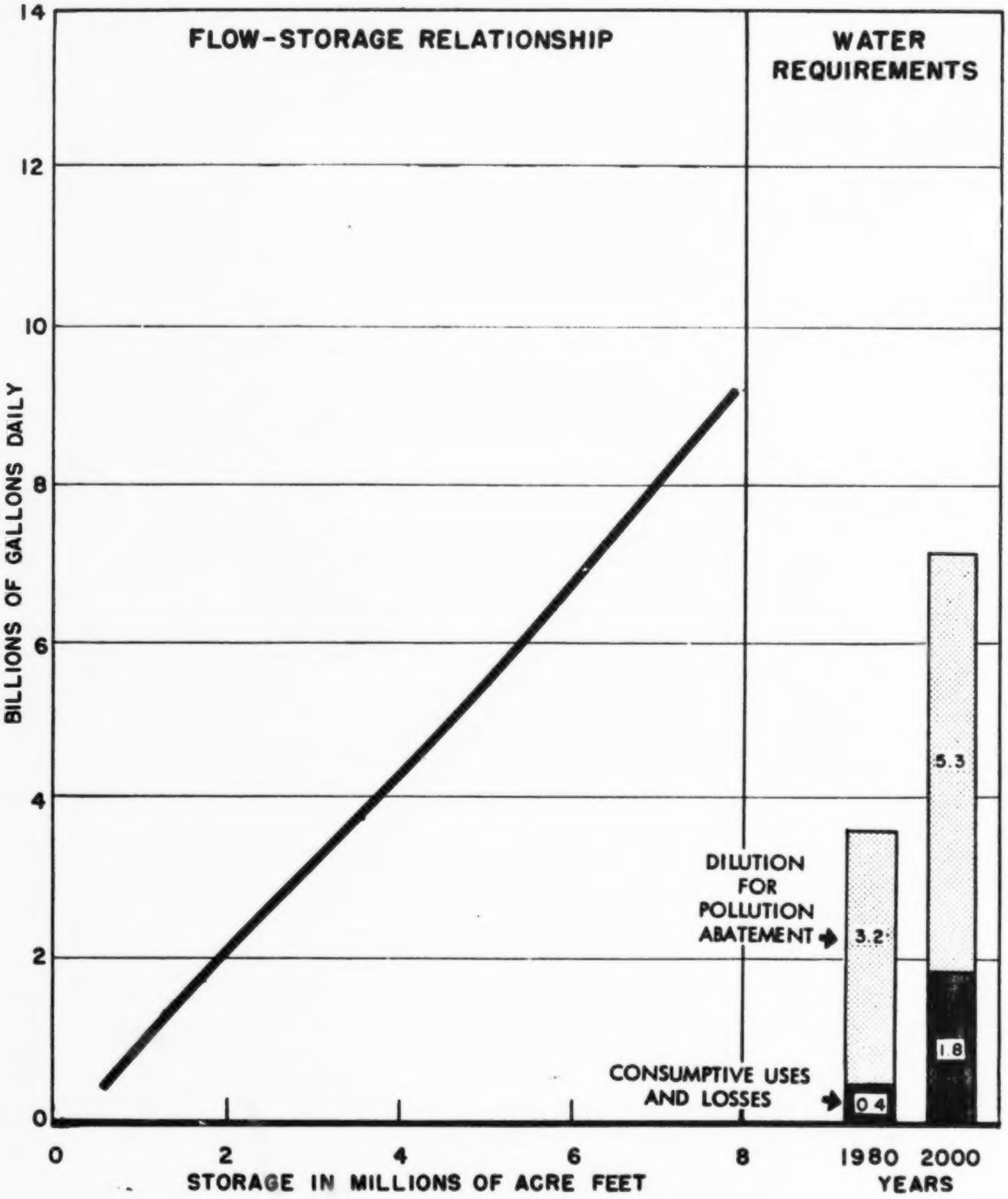


TABLE 52-M.—*Summary: Withdrawals, losses, and flows, Lower Missouri region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	0.1	0.2	1.5
Mining	(1)	(1)	(1)
Manufacturing	.1	.3	.9
Steam-electric power	.9	1.8	3.6
Municipal	.2	.3	.4
Total	1.3	2.6	6.4
Losses:			
Withdrawal uses:			
Agriculture	.1	.2	1.4
Mining	(1)	(1)	(1)
Manufacturing	(1)	(1)	.1
Steam-electric power	...	(1)	(1)
Municipal	(1)	(1)	(1)
Total	.1	.2	1.5
Onsite uses: [2]			
Land treatment and structures	(.1)	.2	.2
Swamps and wetlands [3]	(1)	(1)	(1)
Total	(.1)	.2	.2
Total losses from runoff [2]	.1	.4	1.8
Flows:			
Hydroelectric power	.9	5.4	6.2
Navigation	22.6	22.6	22.6
Sport fish habitat	1.2	1.8	2.1
Waste dilution [4] [5]	1.8	3.2	5.3
Total losses plus waste dilution flows	1.9	3.6	7.1
Maximum low flow that can be sustained [6]			14.5

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

Chart 4-N

UPPER ARKANSAS-RED RIVERS REGION

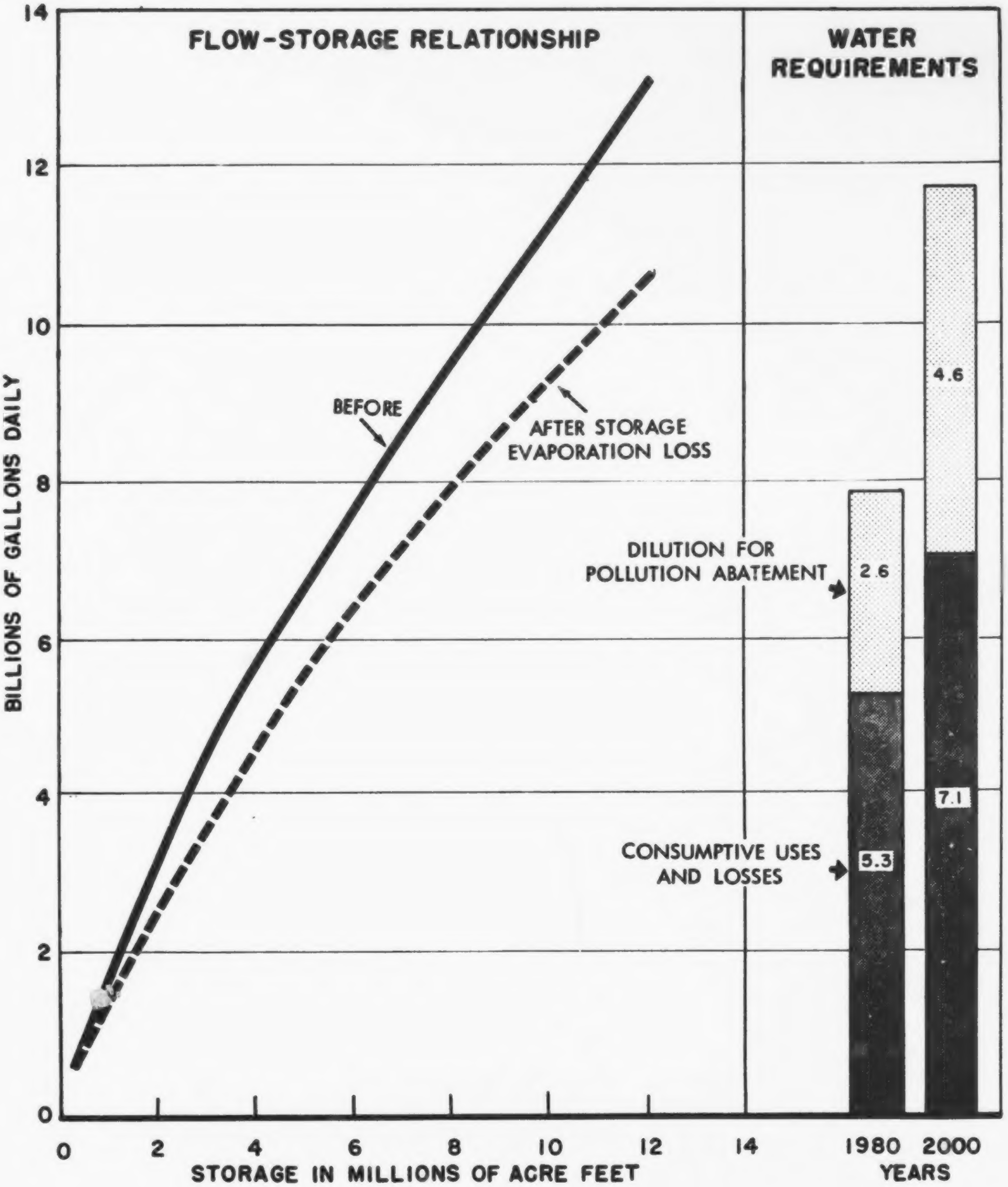


TABLE 52-N.—*Summary: Withdrawals, losses, and flows, Upper Arkansas-White-Red region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	6.2	5.8	6.6
Mining	(1)	.1	.1
Manufacturing	.1	.4	1.3
Steam-electric power	1.8	5.4	8.0
Municipal	.3	.4	.6
Total	8.4	12.1	16.6
Losses:			
Withdrawal uses:			
Agriculture	3.7	3.7	4.6
Mining	(1)	(1)	(1)
Manufacturing	.1	.2	.5
Steam-electric power	.1	.3	.4
Municipal	.1	.1	.1
Total	4.0	4.3	5.6
Onsite uses:[2]			
Land treatment and structures	(.2)	.2	.3
Swamps and wetlands[3]	(1.1)	.8	1.1
Total	(1.3)	1.0	1.4
Total losses from runoff[2]	4.0	5.3	7.1
Flows:			
Hydroelectric power	....	3.6	3.6
Sport fish habitat	1.1	1.8	2.2
Waste dilution[4][5]	13.7	2.6	4.6
Total losses plus waste dilution flows	17.7	7.9	11.7
Maximum low flow that can be sustained[6]			10.5

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

Chart 4–O

LOWER ARKANSAS-WHITE-RED RIVERS REGION

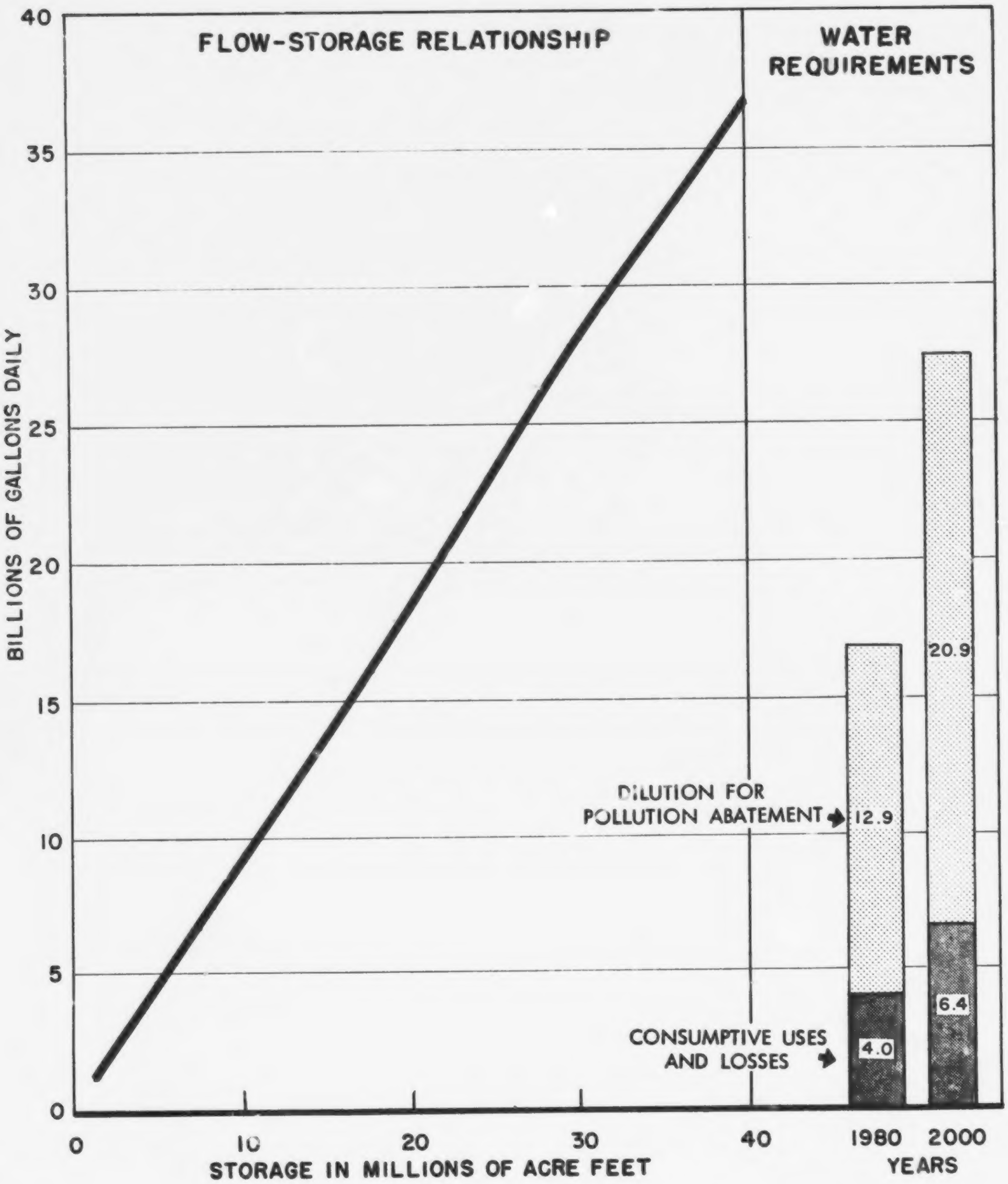


TABLE 52-O.—*Summary: Withdrawals, losses, and flows, Lower Arkansas-White-Red region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	1.5	2.1	3.2
Mining	(1)	.1	.1
Manufacturing	.3	1.0	2.4
Steam-electric power	1.8	3.6	5.4
Municipal	.2	.3	.4
Total	3.8	7.1	11.5
Losses:			
Withdrawal uses:			
Agriculture	1.2	1.8	3.0
Mining	(1)	(1)	(1)
Manufacturing	.1	.3	.6
Steam-electric power	(1)	(1)	.1
Municipal	(1)	(1)	(1)
Total	1.3	2.1	3.7
Onsite uses: [2]			
Land treatment and structures	(.3)	.3	.7
Swamps and wetlands [3]	(1.9)	1.5	2.0
Total	(2.2)	1.8	2.7
Total losses from runoff [2]	1.3	4.0	6.4
Flows:			
Hydroelectric power	5.4	29.5	29.5
Navigation	4.3	7.4	7.2
Sport fish habitat	1.3	1.8	1.9
Waste dilution [4] [5]	14.8	12.9	20.9
Total losses plus waste dilution flows	16.1	16.9	27.3
Maximum low flow that can be sustained [6]			70.3

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

Chart 4-P

WESTERN GULF REGION

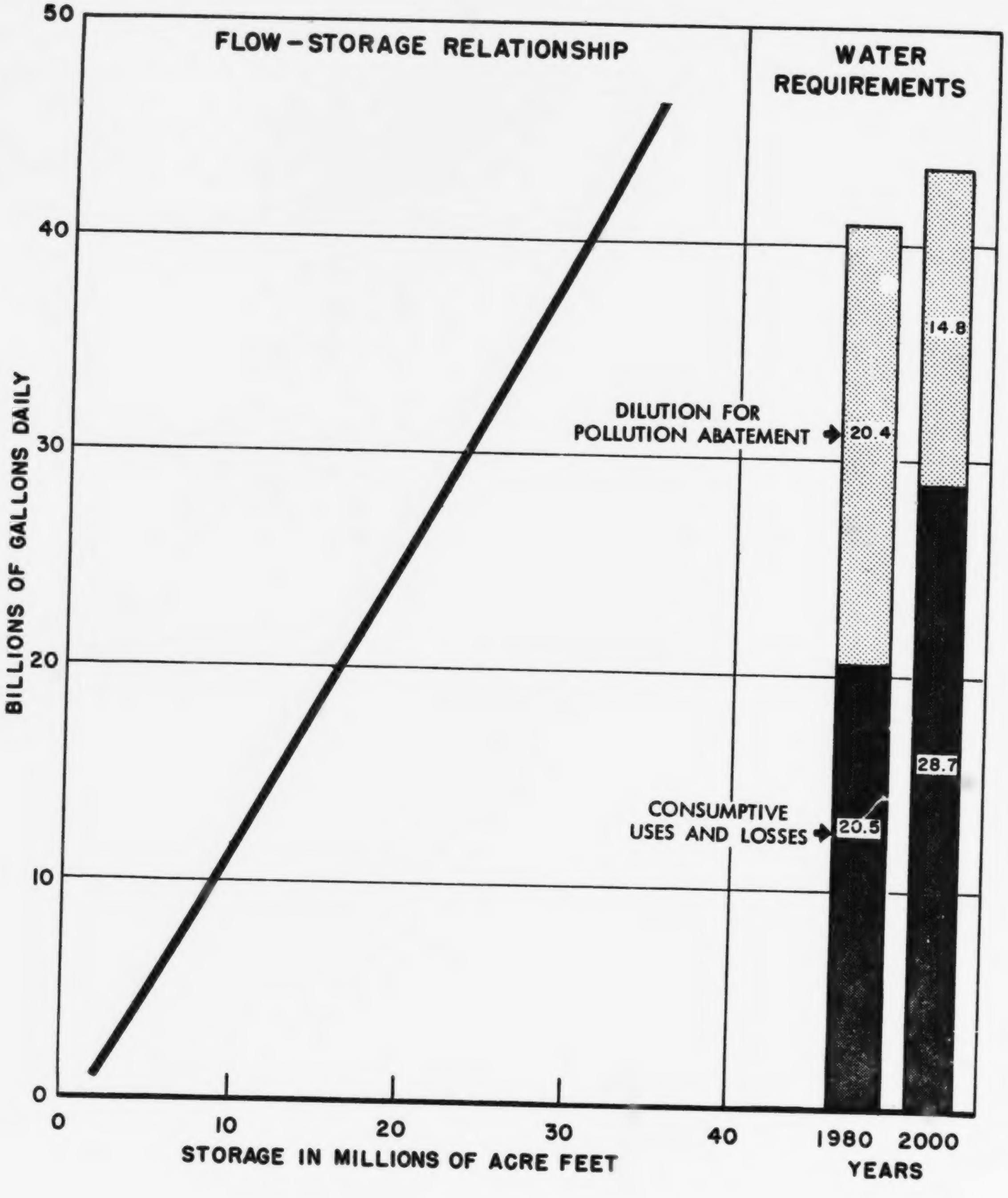


Table 52-P.—*Summary: Withdrawals, losses, and flows, Western Gulf region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	14.3	13.2	14.0
Mining	.2	.2	.3
Manufacturing	3.1	13.1	38.7
Steam-electric power	4.5	15.2	24.1
Municipal	.7	1.3	1.9
Total	22.8	43.0	79.0
Losses:			
Withdrawal uses:			
Agriculture	9.2	8.4	10.0
Mining	.1	.1	.1
Manufacturing	.6	1.7	4.3
Steam-electric power	.1	.3	.5
Municipal	.1	.3	.4
Total	10.1	10.8	15.3
Onsite uses: [1]			
Land treatment and structures	(.2)	.2	.5
Swamps and wetlands [2]	(12.6)	9.4	12.8
Total	(12.8)	9.6	12.3
Total losses from runoff [1]	10.1	20.6	28.7
Flows:			
Hydroelectric power	1.8	8.0	8.0
Navigation		1.4	1.7
Sport fish habitat	.8	2.4	3.5
Waste dilution [3] [4]	23.4	20.4	14.8
Total losses plus waste dilution flows	33.5	40.9	43.5
Maximum low flow that can be sustained [5]			40.4

[1] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[2] Losses from swamps and wetlands include losses from fish hatcheries.

[3] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[4] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[5] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

Chart 4-Q

UPPER RIO GRANDE AND PECOS RIVER REGION

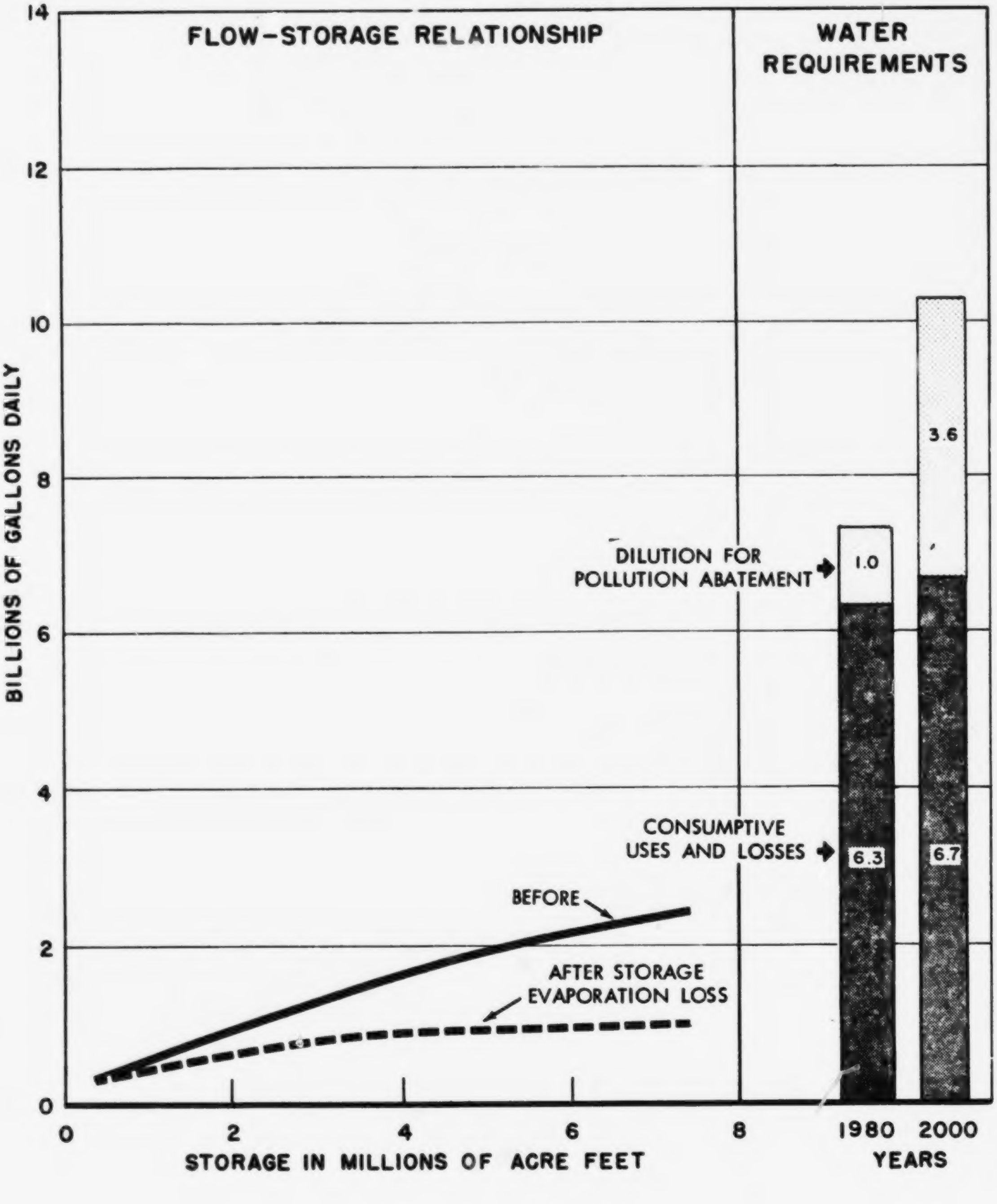


TABLE 52-Q.—*Summary: Withdrawals, losses, and flows, Upper Rio Grande-Pecos region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	8.8	8.2	7.0
Mining	(1)	(1)	.1
Manufacturing	(1)	.1	.7
Steam-electric power	--------	1.8	2.7
Municipal	.1	.2	.3
Total	8.9	10.3	10.8
Losses:			
Withdrawal uses:			
Agriculture	5.1	5.0	4.8
Mining	(1)	(1)	(1)
Manufacturing	(1)	(1)	.1
Steam-electric power	--------	.1	.2
Municipal	(1)	--------	.1
Total	5.1	5.1	5.2
Onsite uses: [2]			
Land treatment and structures	(.1)	.1	.1
Swamps and wetlands [3]	(1.5)	1.1	1.5
Total	(1.6)	1.2	1.6
Total losses from runoff [2]	5.1	6.3	6.7
Flows:			
Hydroelectric power	--------	.9	.9
Sport fish habitat	.7	1.8	2.9
Waste dilution [4] [5]	5.8	1.0	3.6
Total losses plus waste dilution flows	10.9	7.3	10.3
Maximum low flow that can be sustained [6]			1.0

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

CHART 4-R

COLORADO RIVER REGION

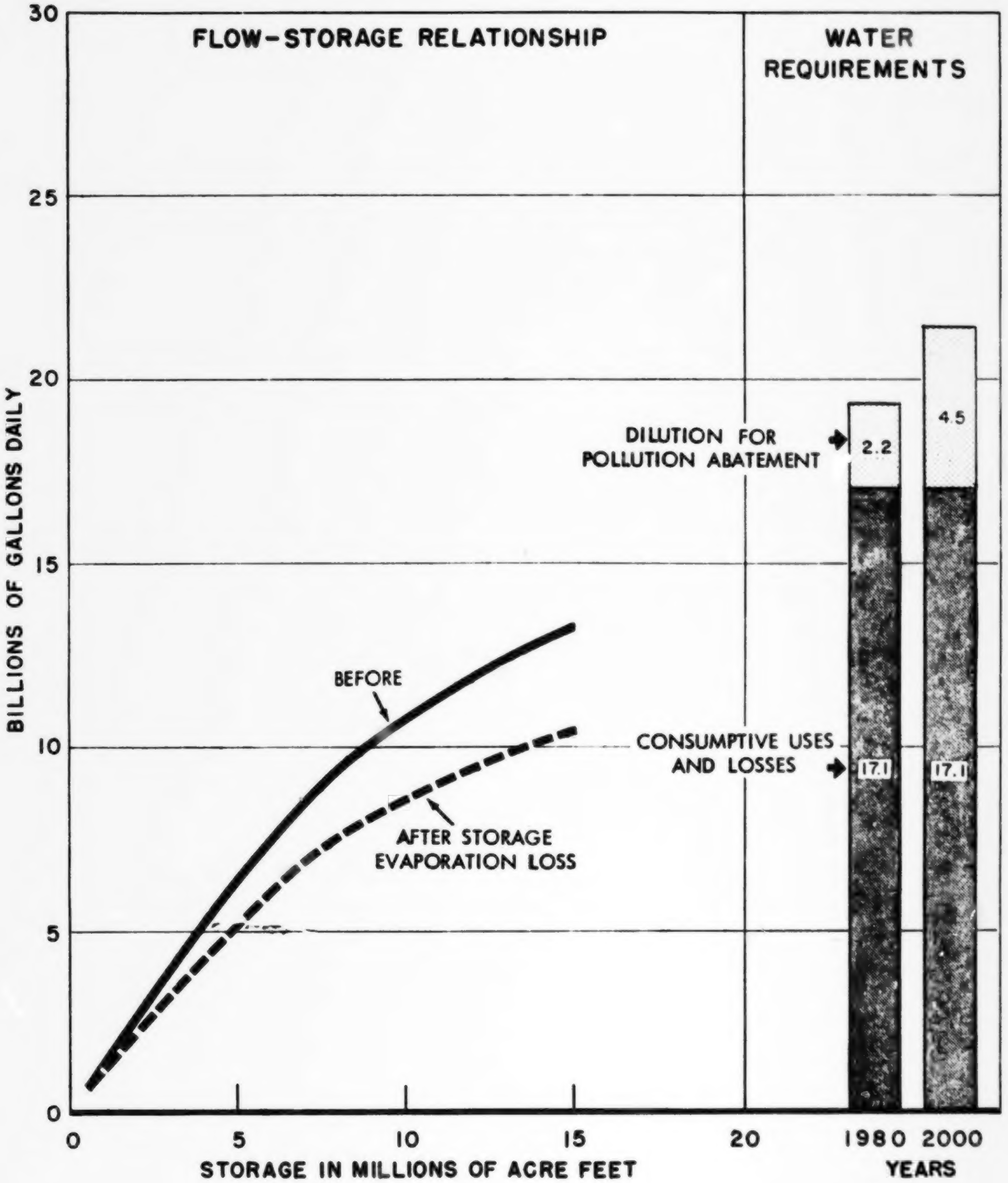


TABLE 52-R.—*Summary: Withdrawals, losses, and flows, Colorado region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	26.4	22.8	20.0
Mining	.1	.7	.7
Manufacturing	(1)	.1	.7
Steam-electric power	....	3.6	8.0
Municipal	.2	.4	.6
Total	26.7	27.6	30.0
Losses:			
Withdrawal uses:			
Agriculture	15.6	14.4	13.2
Mining	(1)	.2	.2
Manufacturing	(1)	(1)	.3
Steam-electric power	....	.3	.6
Municipal	(1)	.1	.1
Total	15.6	15.0	14.4
Onsite uses: [2]			
Land treatment and structures	(.1)	.1	.1
Swamps and wetlands [3]	(2.6)	2.0	2.6
Total	(2.7)	2.1	2.7
Total losses from runoff [2]	15.6	17.1	17.1
Flows:			
Hydroelectric power	8.9	9.8	9.8
Sport fish habitat	3.3	10.0	15.9
Waste dilueion [4] [5]	6.1	2.2	4.5
Total losses plus waste dilution flows	21.7	19.3	21.6
Maximum low flow that can be sustained [6]			10.4

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

CHART 4-S

GREAT BASIN REGION

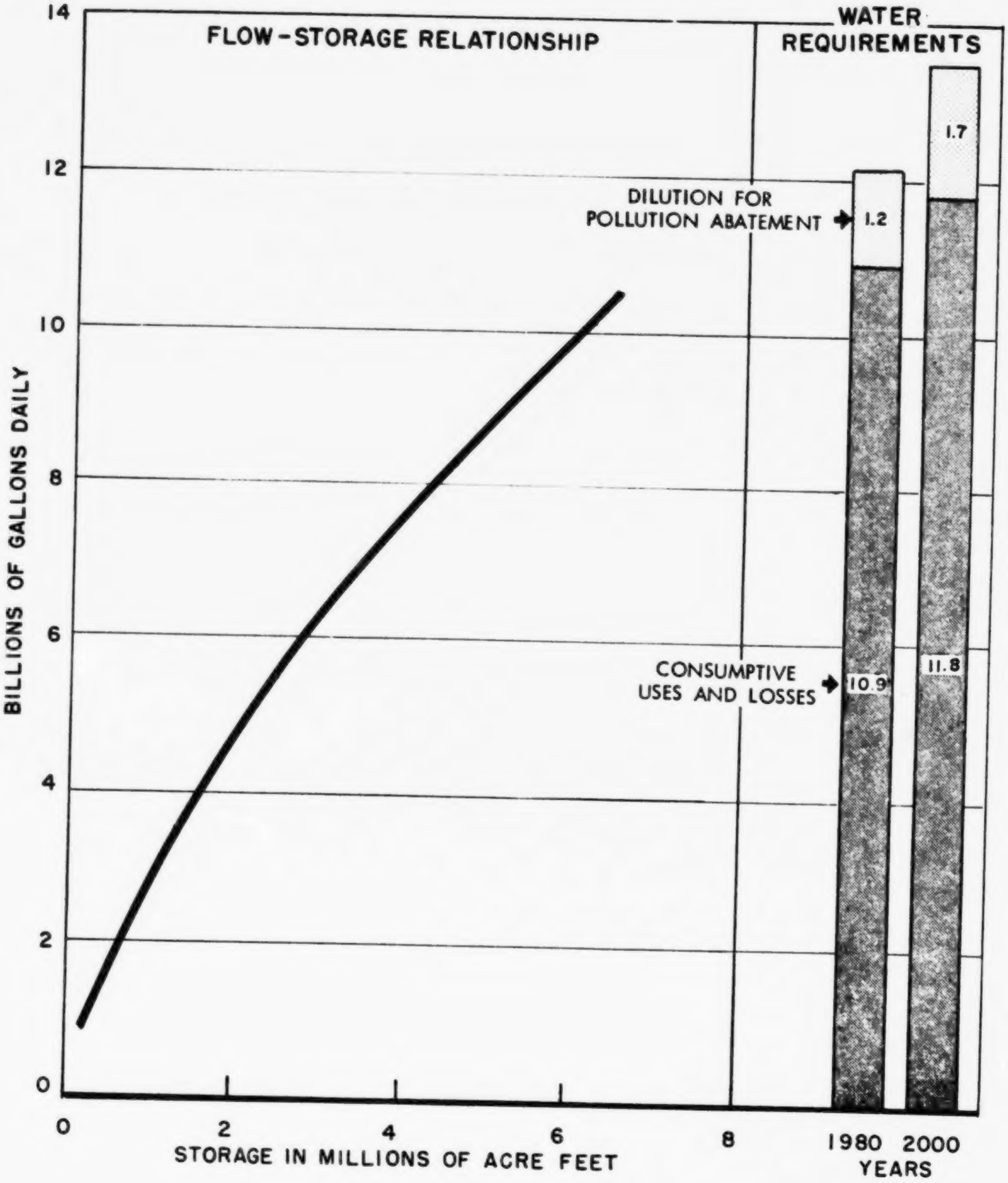


TABLE 52-S.—*Summary: Withdrawals, losses, and flows, Great Basin region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	12.3	10.6	9.2
Mining	.1	(1)	(1)
Manufacturing	.1	.3	.8
Steam-electric power		1.8	2.7
Municipal	.2	.3	.6
Total	12.6	13.0	13.3
Losses:			
Withdrawal uses:			
Agriculture	7.3	6.7	6.1
Mining	(1)	(1)	(1)
Manufacturing	(1)	.1	.2
Steam-electric power		.1	.1
Municipal	(1)	.1	.1
Total	7.3	7.0	6.5
Onsite uses: [2]			
Land treatment and structures	(1)	(1)	(1)
Swamps and wetlands [3]	(5.3)	3.9	5.3
Total	(5.3)	3.9	5.3
Total losses from runoff [3]	7.3	10.9	11.8
Flows:			
Hydroelectric power	.9	2.7	2.7
Sport fish habitat	.8	2.4	4.0
Waste dilution [4] [5]	8.1	1.2	1.7
Total losses plus waste dilution flows	15.4	12.1	13.5
Maximum low flow that can be sustained [6]			9.3

---

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

Chart 4–T

PACIFIC NORTHWEST REGION

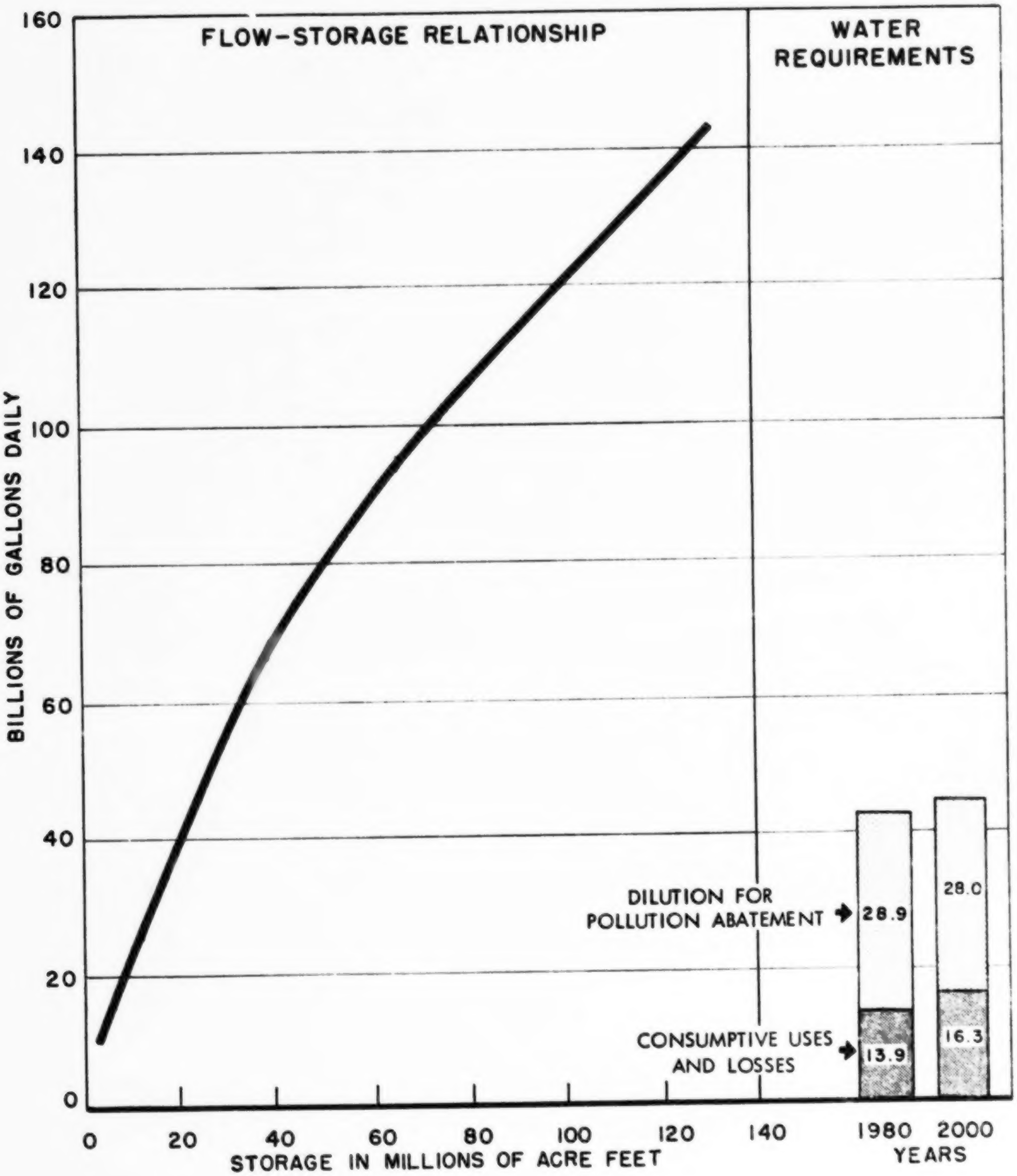


TABLE 52-T.—*Summary: Withdrawals, losses, and flows, Pacific Northwest region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	22.8	20.6	21.8
Mining	(1)	(1)	.1
Manufacturing	1.2	8.5	19.3
Steam-electric power		4.5	17.0
Municipal	.8	1.4	2.3
Total	24.8	35.0	60.5
Losses:			
Withdrawal uses:			
Agriculture	12.5	12.3	13.6
Mining	(1)	(1)	(1)
Manufacturing	.1	.4	.9
Steam-electric power		(1)	(1)
Municipal	.2	.3	.5
Total	12.8	13.0	15.0
Onsite uses: [2]			
Land treatment and structures	(.1)	.1	.2
Swamps and wetlands [3]	(1.1)	.8	1.2
Total	(1.2)	.9	1.4
Total losses from runoff [2]	12.8	13.9	16.3
Flows:			
Hydroelectric power	93.7	133.0	133.9
Navigation	100.8	35.2	37.8
Sport fish habitat	3.1	5.6	8.7
Waste dilution [4] [5]	4.7	28.9	28.0
Total losses plus waste dilution flows	17.5	42.8	44.3
Maximum low flow that can be sustained [6]			136.3

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservcir capacity.

Chart 4-U

CENTRAL PACIFIC REGION

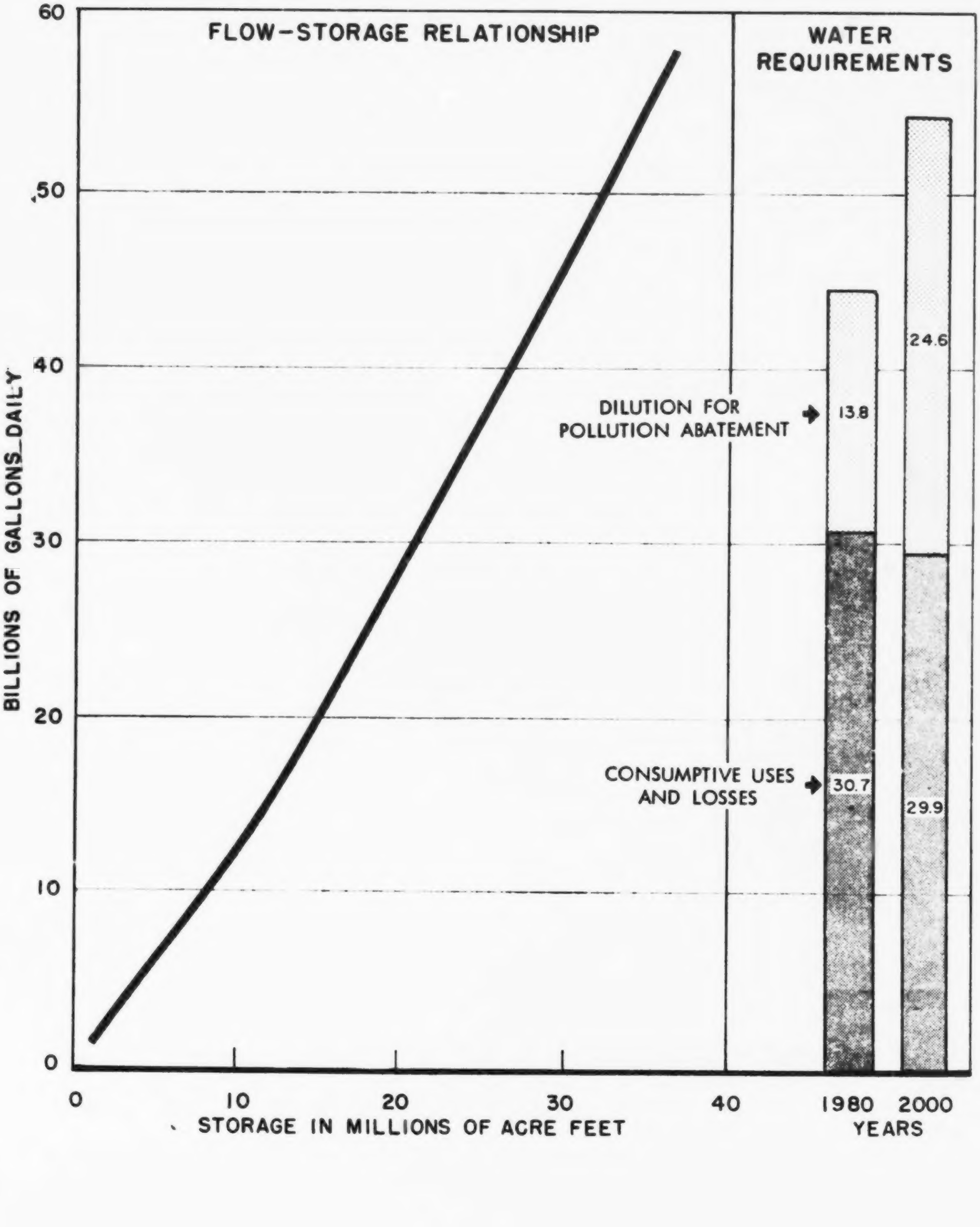


TABLE 52-U.—*Summary: Withdrawals, losses, and flows, Central Pacific region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	47.0	43.5	37.5
Mining	(1)	.1	.2
Manufacturing	.5	1.6	3.7
Steam-electric power	1.8	13.4	25.0
Municipal	.7	1.6	2.7
Total	50.0	60.2	69.1
Losses:			
Withdrawal uses:			
Agriculture	27.6	27.0	24.4
Mining	(1)	(1)	(1)
Manufacturing	.1	.4	1.0
Steam-electric power	(1)	.1	.1
Municipal	.1	.3	.5
Total	27.8	27.8	26.0
Onsite uses: [2]			
Land treatment and structures	(.1)	.1	.1
Swamps and wetlands [3]	(3.8)	2.8	3.8
Total	(3.9)	2.9	3.9
Total losses from runoff [2]	27.8	30.7	29.9
Flows:			
Hydroelectric power	11.6	29.5	29.5
Navigation	3.3	3.3	3.3
Sport fish habitat	3.3	11.7	20.6
Waste dilution [4] [5]	6.1	13.8	24.6
Total losses plus waste dilution flows	33.9	44.5	54.5
Maximum low flow that can be sustained [6]			55.3

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

Chart 4–V

SOUTH PACIFIC REGION

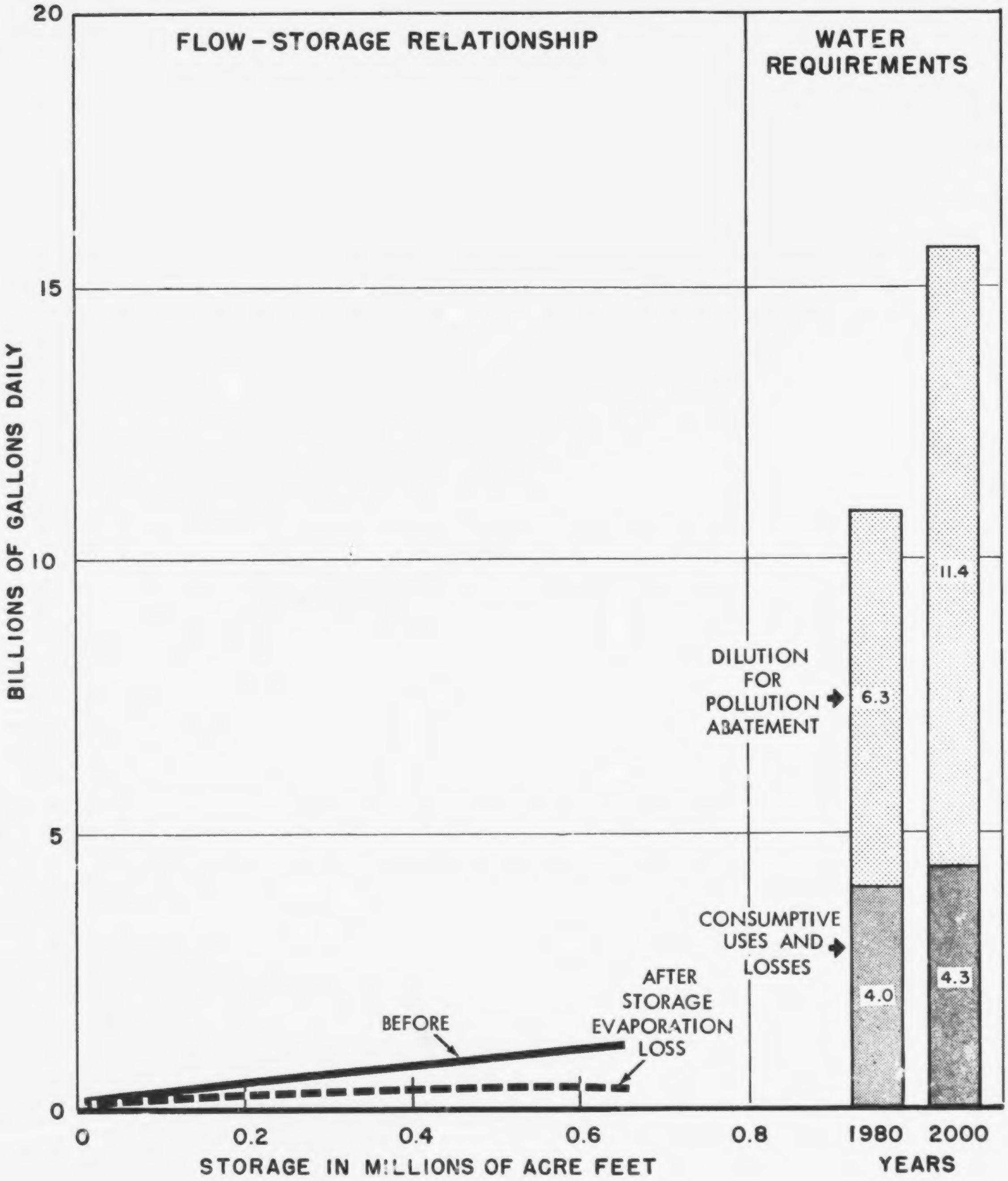


Table 52-V—*Summary: Withdrawals, losses, and flows, South Pacific region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	6.6	5.2	4.6
Mining	(1)	.1	.1
Manufacturing	.4	1.2	2.5
Steam-electric power	2.7	10.7	17.9
Municipal	1.1	2.2	3.4
Total	10.8	19.4	28.5
Losses:			
Withdrawal uses:			
Agriculture	3.9	3.3	3.1
Mining	(1)	(1)	(1)
Manufacturing	.1	.2	.4
Steam-electric power	(1)	(1)	.1
Municipal	.2	.4	.7
Total	4.2	3.9	4.3
Onsite uses: [2]			
Land treatment and structures	0	(1)	(1)
Swamps and wetlands [3]	(1)	(1)	(1)
Total	(1)	(1)	(1)
Total losses from runoff [2]	4.2	4.0	4.3
Flows:			
Sport fish habitat	.6	2.3	3.7
Waste dilution [4] [5]	19.6	6.3	11.4
Total losses plus waste dilution flows	23.8	10.3	15.7
Maximum low flow that can be sustained [6]			0.3

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

Table 52-V.—*Summary: Withdrawals, losses, and flows, South Pacific region*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	6.6	5.2	4.6
Mining	(1)	.1	.1
Manufacturing	.4	1.2	2.5
Steam-electric power	2.7	10.7	17.9
Municipal	1.1	2.2	3.4
Total	10.8	19.4	28.5
Losses:			
Withdrawal uses:			
Agriculture	3.9	3.3	3.1
Mining	(1)	(1)	(1)
Manufacturing	.1	.2	.4
Steam-electric power	(1)	(1)	.1
Municipal	.2	.4	.7
Total	4.2	3.9	4.3
Onsite uses: [2]			
Land treatment and structures	0	(1)	(1)
Swamps and wetlands [3]	(1)	(1)	(1)
Total	(1)	(1)	(1)
Total losses from runoff [2]	4.2	4.0	4.3
Flows:			
Sport fish habitat	.6	2.3	3.7
Waste dilution [4, 5]	19.6	6.3	11.4
Total losses plus waste dilution flows	23.8	10.3	15.7
Maximum low flow that can be sustained [6]			0.3

[1] Less than 50,000,000 gallons per day.

[2] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[3] Losses from swamps and wetlands include losses from fish hatcheries.

[4] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage, waste dilution flows are for level of treatment that minimizes required dilution.

[5] 1954 waste dilution estimated on basis of 70-percent treatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[6] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

TABLE 52-W.—*Summary: Withdrawals, losses, and flows, U.S. total*

[Billions of gallons per day]

	1954	1980	2000
Withdrawals:			
Agriculture	176.1	167.2	184.2
Mining	1.5	2.7	3.4
Manufacturing	31.9	101.6	229.2
Steam-electric power	74.1	258.9	429.4
Municipal	16.7	28.6	42.2
Total	300.3	559.0	888.4
Losses:			
Withdrawal uses:			
Agriculture	103.9	104.5	126.3
Mining	.3	.6	.7
Manufacturing	2.8	8.7	20.8
Steam-electric power	.4	1.7	2.9
Municipal	2.1	3.7	5.5
Total	109.5	119.2	156.2
Onsite uses: [1]			
Land treatment and structures	(3.5)	4.0	7.0
Swamps and wetlands [2]	(89.5)	66.7	89.9
Total	(93.0)	70.7	96.9
Total losses from runoff [1]	109.5	189.9	253.1
Flows:			
Hydroelectric power	375.0	616.1	636.5
Navigation	281.0	238.4	221.4
Sport fish habitat	78.0	171.0	241.4
Waste dilution [3] [4]	512.5	332.2	446.5
Total losses plus waste dilution flows	622.0	522.7	699.6
Maximum low flow that can be sustained [5]			1,080.8

[1] Onsite uses: "Losses" for 1954 are estimated by a backward extrapolation from 1980. Such "losses" are not to be deducted from runoff, since runoff already incorporates effects of onsite water use. Figures for 1980 and 2000 are increases above 1954 losses and therefore should be charged against runoff.

[2] Losses from swamps and wetlands include losses from fish hatcheries.

[3] Total streamflow needed to maintain dissolved oxygen at average of 4 milligrams per liter, for level of treatment that minimizes total cost of treatment and storage. In regions of water shortage waste dilution flows are for level of treatment that minimizes required dilution.

[4] 1954 waste dilution estimated on basis of 70-percentt reatment for municipal and 50-percent treatment for industrial wastes, both higher than actually prevailed.

[5] Maximum low flow before depletions from use but after estimated losses from added reservoir capacity.

NOTE.—Because of rounding regional details shown may not add to U.S. totals.

CHART 5

RATIO OF PROJECTED POPULATION GROWTH BY WATER RESOURCE REGION TO PROJECTED AVERAGE POPULATION GROWTH OF CONTINENTAL UNITED STATES

1960 - 1980 and 1980 - 2000; U.S. AVERAGE =1.00

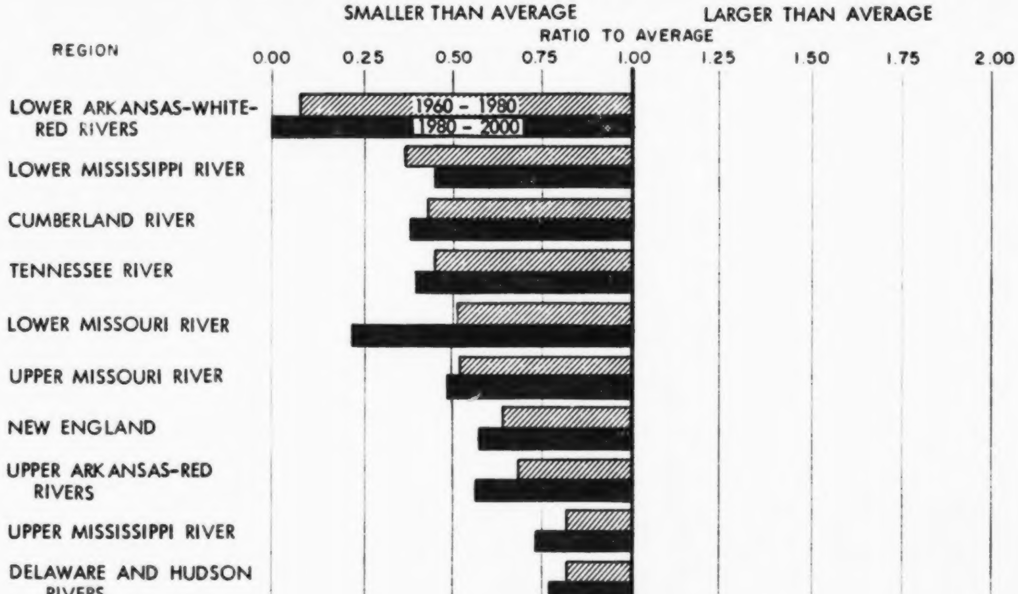


TABLE 53-A.—*Distribution of required flow by uses (withdrawal losses, onsite losses, and waste dilution; minimum cost program), 1980*

[Percent]

	Agriculture	Mining	Manufacturing	Thermal power	Municipal	Land treatment	Fish and wildlife habitat	Subtotal: All losses	Waste dilution flow
New England	0.8		3.7	0.1	1.0	3.1	2.2	10.9	89.1
Delaware and Hudson	2.3	0.1	3.2	.3	2.7	−.6	6.9	14.9	85.1
Chesapeake Bay	.9	.02	1.3	.01	.6	.6	2.8	6.2	93.8
Southeast	3.2	.01	1.9	.02	.2	.6	19.8	25.7	74.3
Eastern Great Lakes	.9	.1	2.6	.1	1.7	.8	5.0	11.2	88.8
Western Great Lakes	.9	.02	2.2	.02	.9	.2	7.6	11.8	88.2
Ohio	2.2	.4	4.5	.5	1.2	1.8	.6	11.2	88.8
Cumberland	.4	.01	.04		.2	1.1	.5	2.2	97.8
Tennessee	.5	.01	.7	.01	.1	.5	.2	2.0	98.0
Upper Mississippi	2.0	.1	1.1	.03	.6	.9	11.9	16.6	83.4
Lower Mississippi	8.5	.1	.4	.8	.2	.7	32.0	42.7	57.3
Upper Missouri	44.8	.05	.2	.3	.4	2.0	39.3	87.0	13.0
Lower Missouri	5.6	.01	.8	.01	.8	4.5	.3	12.0	88.0
Upper Arkansas-White-Red	47.1	.4	2.0	3.7	1.0	2.5	10.5	67.2	32.8
Lower Arkansas-White-Red	10.7	.1	1.7	.2	.2	1.6	9.0	23.5	76.5
Western Gulf	20.6	.2	4.3	.8	.6	.5	23.1	50.1	49.9
Upper Rio Grande and Pecos	67.7	.4	.1	1.4	.4	1.4	15.0	86.4	13.6
Colorado	74.6	1.3	.2	1.5	.4	.3	10.1	88.4	11.6
Great Basin	55.5		.7	.6	.6	.04	32.7	90.1	9.9
Pacific Northwest	28.8	.01	.9		.7	.2	1.9	32.5	67.5
Central Pacific	60.8	.02	.9	.1	.7	.2	6.2	68.9	31.1
South Pacific	32.1	.1	1.7	.4	4.2	.03	.2	38.7	61.3
United States	20.0	.1	1.7	.3	.7	.8	12.8	36.4	63.6

TABLE 53-B.—*Distribution of required flow by uses (withdrawal losses, onsite losses, and waste dilution; minimum cost program), 2000*

[Percent]

	Agriculture	Mining	Manufacturing	Thermal power	Municipal	Land treatment	Fish and wildlife habitat	Subtotal: All losses	Waste dilution flow
New England	1.5		5.6	0.1	1.0	2.5	2.2	12.9	87.1
Delaware and Hudson	2.3	0.1	4.5	.3	2.7	−1.0	6.5	15.4	84.6
Chesapeake Bay	4.6	.04	2.3	.02	.8	.3	3.5	11.6	88.4
Southeast	8.2	.01	3.4	.03	.3	.9	20.0	32.8	67.2
Eastern Great Lakes	2.1	.1	2.8	.05	1.4	.1	3.8	10.3	89.7
Western Great Lakes	2.0	.02	4.2	.02	.8	.2	6.1	13.3	86.7
Ohio	5.3	.3	5.3	.4	1.0	1.5	.5	14.3	85.7
Cumberland	.9	.005	.04	.5	.1	1.0	.4	2.9	97.1
Tennessee	1.1	.02	1.4	.02	.2	.9	.2	3.8	96.2
Upper Mississippi	14.1	.2	1.9	.04	.8	1.7	14.9	33.6	66.4
Lower Mississippi	8.6	.04	.6	.8	.2	.9	26.2	37.3	62.7
Upper Missouri	40.1	.03	.2	.4	.3	3.0	34.5	78.5	21.5
Lower Missouri	20.0	.01	1.4	.02	.5	3.3	.3	25.5	74.5
Upper Arkansas-White-Red	39.1	.3	4.0	3.7	1.0	2.8	9.8	60.7	39.3
Lower Arkansas-White-Red	10.9	.04	2.3	.2	.2	2.4	7.3	23.3	76.7
Western Gulf	22.9	.2	10.0	1.3	.8	1.3	29.5	66.0	34.0
Upper Rio Grande and Pecos	46.4	.3	.7	1.5	.5	1.3	14.4	65.1	34.9
Colorado	60.8	1.1	1.2	3.0	.6	.4	12.1	79.2	20.8
Great Basin	44.9		1.5	.7	.9	.1	39.3	87.4	12.6
Pacific Northwest	30.8	.02	2.1	.01	1.0	.4	2.6	36.9	63.1
Central Pacific	44.8	.03	1.7	.2	1.0	.2	6.9	54.8	45.2
South Pacific	19.5	.1	2.6	.5	4.3	.02	.2	27.2	72.8
United States	18.1	.1	3.0	.4	.8	1.0	12.8	36.2	63.8

CHART 6

PERCENTAGE DISTRIBUTION OF REQUIRED FLOW BETWEEN LOSSES AND WASTE DILUTION
1980

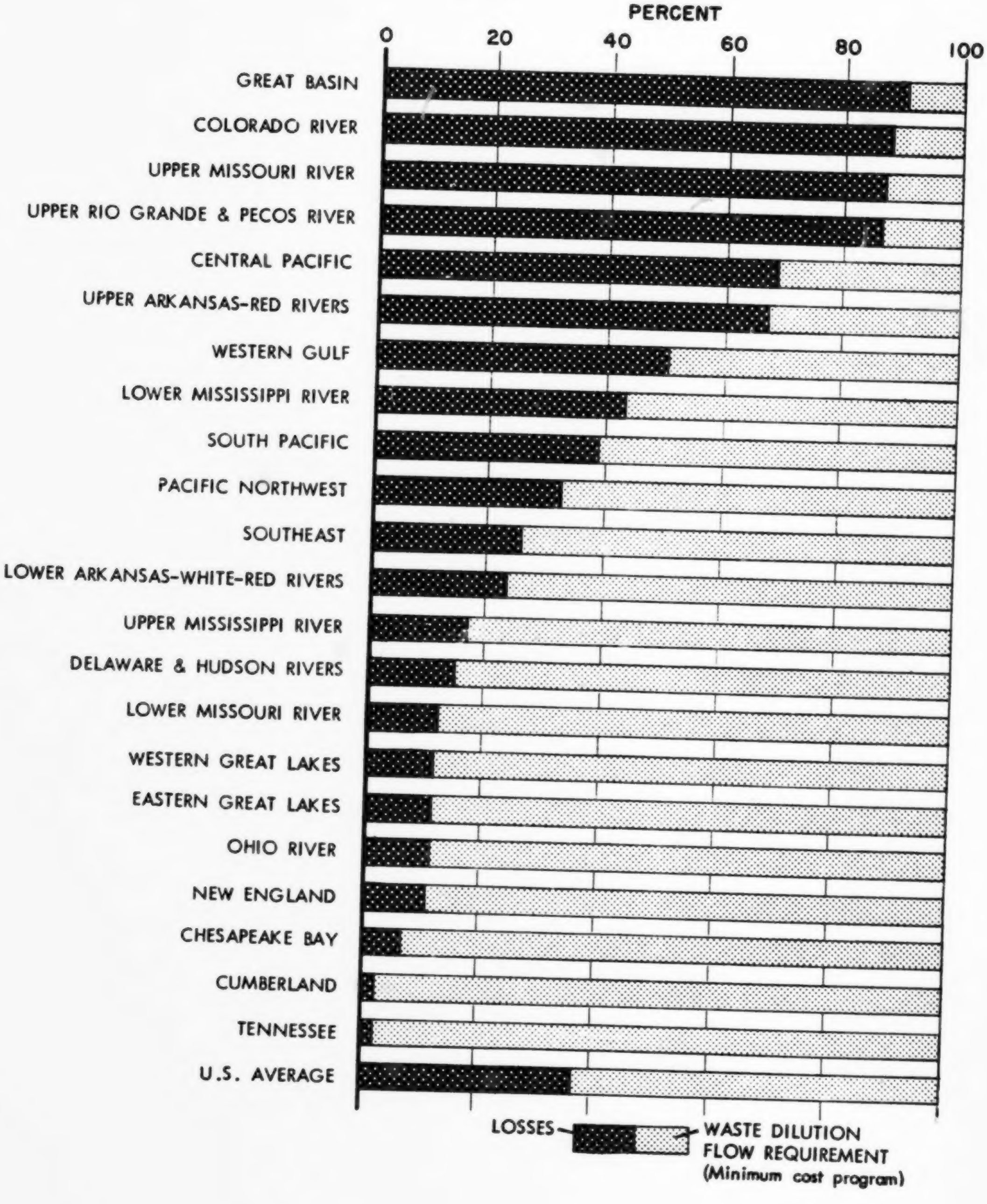


Table 54–A.—*Ratio of maximum obtainable supply to minimum flow requirements, 1980*

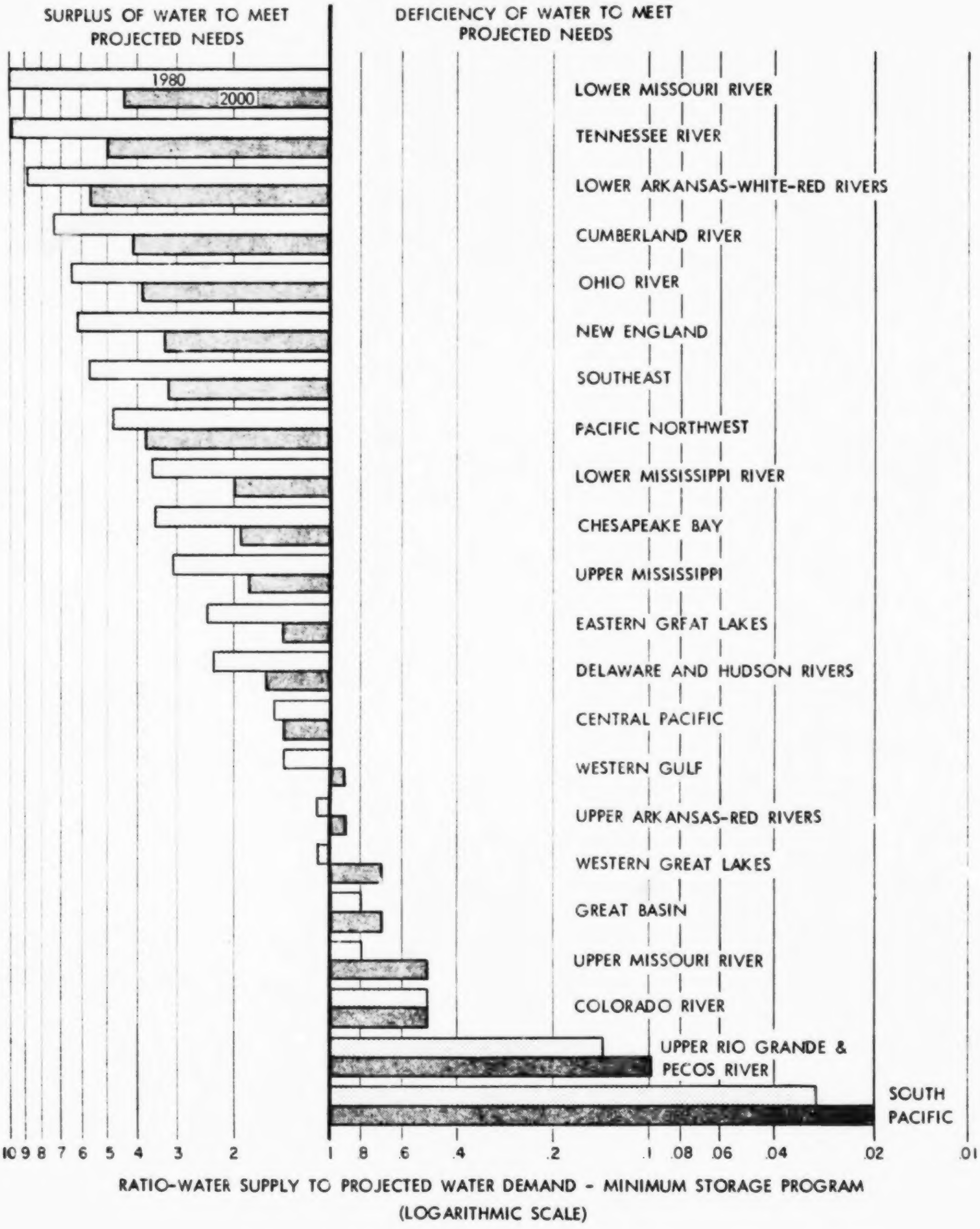
	Maximum flow obtainable (billion gallons per day)	Flow required for minimum storage program (billion gallons per day)	Ratio of supply to demand	Rank order
Lower Missouri	22.0	2.2	10.0	1.0
Tennessee	42.6	4.3	9.9	2.0
Lower Arkansas-White-Red	70.0	7.9	8.9	3.0
Cumberland	15.4	2.1	7.3	4.0
Ohio	108.5	17.0	6.4	5.0
New England	65.0	10.5	6.2	6.0
Southeast	207.0	36.4	5.7	7.0
Pacific Northwest	136.0	28.7	4.7	8.0
Lower Mississippi	49.1	13.7	3.6	9.0
Chesapeake Bay	50.8	14.7	3.5	10.0
Upper Mississippi	58.9	19.1	3.1	11.0
Eastern Great Lakes	38.6	15.8	2.4	12.0
Delaware and Hudson	31.0	13.5	2.3	13.0
Central Pacific	55.3	35.9	1.5	14.0
Western Gulf	40.9	29.2	1.4	15.0
Upper Arkansas-White-Red	10.5	7.9	1.3	16.0
Western Great Lakes	40.0	36.2	1.1	17.0
Great Basin	9.3	12.1	.8	18.5
Upper Missouri	26.7	33.6	.8	18.5
Colorado	10.4	19.3	.5	20.0
Upper Rio Grande and Pecos	1.0	7.3	.14	21.0
South Pacific	.3	10.6	.03	22.0

Table 54–B.—*Ratio of maximum obtainable supply to minimum flow requirements, 2000*

	Maximum flow obtainable (billion gallons per day)	Flow required for minimum storage program (billion gallons per day)	Ratio of supply to demand	Rank order
Lower Arkansas-White-Red	70.0	12.4	5.6	1.0
Tennessee	42.6	8.6	5.0	2.0
Lower Missouri	22.0	5.0	4.4	3.0
Cumberland	15.4	3.8	4.1	4.0
Ohio	108.5	28.1	3.9	5.0
Pacific Northwest	136.0	35.8	3.8	6.0
New England	65.0	19.5	3.3	7.0
Southeast	207.0	64.9	3.2	8.0
Lower Mississippi	49.1	24.8	2.0	9.0
Chesapeake Bay	50.8	27.0	1.9	10.0
Upper Mississippi	58.9	32.7	1.8	11.0
Delaware and Hudson	31.0	19.8	1.6	12.0
Eastern Great Lakes	38.6	26.7	1.4	13.5
Central Pacific	55.3	39.8	1.4	13.5
Upper Arkansas-White-Red	10.5	11.7	.9	15.5
Western Gulf	40.9	43.5	.9	15.5
Western Great Lakes	40.0	59.1	.7	17.5
Great Basin	9.3	13.5	.7	17.5
Upper Missouri	26.7	51.1	.5	19.5
Colorado	10.4	21.7	.5	19.5
Upper Rio Grande and Pecos	1.0	10.3	.10	21.0
South Pacific	.3	15.7	.02	22.0

CHART 7

RATIO OF MAXIMUM OBTAINABLE SUPPLY TO MINIMUM FLOW REQUIREMENT 1980 and 2000



APPENDIX

APPENDIX I

CALCULATED RISK[1]

The amount of storage required for a given flow assured 100 percent of the time is successively greater than the amount needed to assure the same flow for 95, 90, 80 percent of the time and so forth. For purposes of this discussion "95 percent of the time" should be understood as meaning "1 year out of 20" in which streamflow would fall below the given amount. During the "1 year" in which a deficiency of flow would be anticipated, it is likely that in the East the period of shortage would be 1 or 2 months, or perhaps even longer. In the West, where a higher degree of regulation would presumably exist, the period of shortage might be the entire 12 months.

TABLE A

TABLE A.—*Regional supplies that can be made available from storage for indicated percent of time*

	Storage	Flow for indicated percent of time		
		95	90	80
	Thousand acre-feet	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*
New England	1,300	14,000	18,000	20,000
Delaware-Hudson	590	8,100	9,800	11,000
Chesapeake Bay	960	13,000	16,000	18,000
Southeast	4,900	54,000	66,000	73,000
Western Great Lakes	780	16,000	19,000	21,000
Eastern Great Lakes	720	7,500	9,600	10,000
Ohio River	4,100	24,200	31,000	34,000
Cumberland	160	4,000	5,000	5,600
Tennessee	400	16,000	22,000	25,000
Upper Mississippi	1,100	18,000	22,000	24,000
Upper Missouri	340	3,500	4,400	4,900
Lower Missouri	660	3,200	3,500	4,100
Upper Arkansas-Red	250	1,900	2,300	2,600
Lower Arkansas-Red-White	1,400	7,800	9,100	11,000
Lower Mississippi	900	7,700	9,800	11,000
Upper Rio Grande-Pecos				
Western Gulf	1,300	7,000	8,000	10,000
Colorado River	90	680	880	950
Great Basin	72	790	1,000	1,100
South Pacific				
Central Pacific	880	6,000	7,000	8,400
Pacific Northwest	2,600	29,000	37,000	40,000

TABLE A.—*Regional supplies that can be made available from storage for indicated percent of time*—Continued

	Storage	Flow for indicated percent of time		
		95	90	80
	Thousand acre-feet	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*
New England	1,900	17,000	21,000	23,000
Delaware-Hudson	900	9,500	11,000	12,000
Chesapeake Bay	1,400	15,000	18,000	20,000
Southeast	7,800	65,000	78,000	85,000
Western Great Lakes	1,100	20,000	21,000	22,000
Eastern Great Lakes	1,100	9,000	11,000	12,000
Ohio River	5,200	27,000	34,000	38,000
Cumberland	288	4,800	6,000	6,700
Tennessee	600	18,000	24,000	27,000
Upper Mississippi	2,300	23,000	28,000	30,000
Upper Missouri	660	4,600	5,900	6,300
Lower Missouri	840	3,900	4,200	5,000
Upper Arkansas-Red	410	2,300	2,900	3,300
Lower Arkansas-Red-White	2,500	12,000	12,000	16,000
Lower Mississippi	1,800	11,000	14,000	15,000
Upper Rio Grande-Pecos				
Western Gulf	1,700	8,200	9,600	12,000
Colorado River	120	780	1,000	1,100
Great Basin	100	900	1,200	1,300
South Pacific				
Central Pacific	1,800	8,800	11,000	12,000
Pacific Northwest	6,650	43,000	52,000	59,000

	Storage	Flow for indicated percent of time		
		95	90	80
	Thousand acre-feet	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*
New England	4,200	24,000	29,000	32,000
Delaware-Hudson	2,000	13,000	15,000	17,000
Chesapeake Bay	3,400	22,000	25,000	28,000
Southeast	14,000	86,000	96,000	110,000
Western Great Lakes	2,800	26,000	28,000	30,000
Eastern Great Lakes	2,200	12,000	15,000	17,000
Ohio River	7,200	34,000	40,000	46,000
Cumberland	620	6,300	7,500	8,000
Tennessee	1,200	25,000	30,000	32,000
Upper Mississippi	5,200	33,000	36,000	40,000
Upper Missouri	1,200	6,400	7,400	8,600
Lower Missouri	1,300	5,000	5,600	6,600
Upper Arkansas-Red	720	3,200	3,900	4,400
Lower Arkansas-Red-White	5,000	18,000	21,000	24,000
Lower Mississippi	3,200	15,000	18,000	20,000
Upper Rio Grande-Pecos				
Western Gulf	3,800	15,000	17,000	19,000
Colorado River	230	1,200	1,300	1,500
Great Basin	240	1,400	1,600	1,900
South Pacific				
Central Pacific	3,100	13,000	15,000	17,000
Pacific Northwest	9,300	52,000	60,000	69,000

---

[1] Based on table A, prepared by Roy E. Oltman, U.S. Geological Survey.

Preceding page blank

Table A.—*Regional supplies that can be made available from storage for indicated percent of time*—Continued

	Storage	Flow for indicated percent of time		
		95	90	80
	Thousand acre-feet	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*
New England	7,300	34,000	37,000	44,000
Delaware-Hudson	3,800	19,000	20,000	23,000
Chesapeake Bay	6,000	30,000	33,000	37,000
Southeast	25,000	120,000	130,000	150,000
Western Great Lakes	5,100	33,000	34,000	37,000
Eastern Great Lakes	3,700	18,000	20,000	23,000
Ohio River	11,000	45,000	51,000	60,000
Cumberland	1,100	7,800	8,800	10,000
Tennessee	2,500	31,000	37,000	40,000
Upper Mississippi	8,700	42,000	46,000	52,000
Upper Missouri	2,100	9,000	10,000	12,000
Lower Missouri	2,300	7,900	8,600	10,000
Upper Arkansas-Red	1,200	4,800	5,400	6,200
Lower Arkansas-Red-White	9,400	30,000	33,000	39,000
Lower Mississippi	5,500	22,000	24,000	28,000
Upper Rio Grande-Pecos				
Western Gulf	5,500	19,000	22,000	25,000
Colorado River	380	1,600	1,800	2,100
Great Basin	420	2,000	2,200	2,400
South Pacific				
Central Pacific	4,300	19,000	22,000	25,000
Pacific Northwest	16,000	73,000	80,000	93,000

	Storage	Flow for indicated percent of time		
		95	90	80
	Thousand acre-feet	*Cubic feet per second*	*Cubic feet per second*	*Cubic feet per second*
New England	13,300	48,000	54,000	60,000
Delaware-Hudson	6,100	24,000	26,000	29,000
Chesapeake Bay	10,200	42,000	46,000	50,000
Southeast	42,500	160,000	170,000	190,000
Western Great Lakes	10,400	44,000	49,000	50,000
Eastern Great Lakes	6,800	26,000	29,000	33,000
Ohio River	17,400	63,000	70,000	80,000
Cumberland	1,800	10,000	11,000	12,000
Tennessee	5,450	40,000	47,000	50,000
Upper Mississippi	14,300	55,000	64,000	68,000
Upper Missouri	3,300	12,000	14,000	16,000
Lower Missouri	3,500	11,000	12,000	14,000
Upper Arkansas-Red	1,800	6,300	7,000	8,200
Lower Arkansas-Red-White	14,300	42,000	46,000	55,000
Lower Mississippi	8,300	29,000	32,000	37,000
Upper Rio Grande-Pecos				
Western Gulf	7,850	25,000	30,000	33,000
Colorado River	685	2,400	2,600	2,900
Great Basin	695	2,800	3,000	3,200
South Pacific				
Central Pacific	7,650	25,000	28,000	32,000
Pacific Northwest	24,400	95,000	100,000	120,000

Notes for Table A

PROBABILITY OF SUPPLIES FROM SPECIFIC STORAGE DEVELOPMENT

The attached table shows estimated regional supplies that can be developed from specific regional storages for 95, 90, and 80 percent of the time. The specific regional storages are the same as listed in table 3 of Select Committee Print No. 3 except that the storages in the last column of table 3 have been replaced by smaller storages (those needed to produce the 60 percent flows 100 percent of the time).

The 95, 90, and 80 percent probabilities mean 19 out of 20, 9 out of 10, and 4 out of 5 years, respectively. They are not applicable as 348, 330, and 293 days in a year.

No data are listed for the Upper Rio Grande-Pecos and South Pacific Regions because current appropriations exceed supplies or because water imports make the supply situation too complex for a probability analysis.

Table B.—*Storage requirements to yield minimum flows for the minimum cost program, 1980, 100 percent and 95 percent of the time*[1]

	Required flow (million gallons per day)	Storage to yield required flows (thousand acre-feet)—	
		100 percent of time	95 percent of time
New England	14,200	3,400	3,400
Delaware and Hudson	13,800	6,100	4,875
Chesapeake Bay	24,000	11,200	8,400
Southeast	75,300	28,000	24,000
Eastern Great Lakes	15,800	8,500	6,200
Western Great Lakes	36,200	34,000	18,500
Ohio River	19,400	10,100	6,100
Cumberland	7,700	3,300	2,550
Tennessee	24,400	6,400	4,600
Upper Mississippi	30,400	14,000	10,700
Lower Mississippi	22,200	15,800	10,500
Lower Missouri	3,600	3,600	1,500
Lower Arkansas-White-Red	14,900	20,000	6,800
Eastern United States		164,400	108,125

[1] See note to table A for interpretation of "95 percent of the time." Flows in table A are in cubic feet per second. For this table they have been converted to millions of gallons per day.

A comparison was made between storage required to assure flow 100 percent of the time and 95 percent of the time for the minimum cost program for 1980. Since the flow storage relationships were prepared only for "flow still available" rather than for flow prior to depletion, the comparison could be made only for the 13 eastern regions, in which present losses from use are negligible. The comparison is shown in table B.

For the 13 regions, accepting the risk of a shortage 1 year out of 20 would reduce total storage requirements by about one-third. In certain regions the reduction is even greater—two-thirds in the Lower Arkansas-White-Red and almost 60 percent in the Lower Missouri.

The question is whether the saving in storage costs is great enough to warrant the disadvantage of water shortage "once every 20 years." Since the minimum cost program entails storage costs of $537 million annually for the United States, a saving of one-third of capacity (assuming that in the West the savings would be the same as in the East) would mean an annual saving, roughly, of $177 million for the country as a whole.[2] At the 1980 projected level of population, 244 million, this would amount to 73 cents per capita per year, or about $15 per capita over a 20-year period. This, then, is an approximate measure of the benefits to be gained in money terms by assuming the risk of periodic (1 year in 20) water shortage.

There are benefits and costs in nonmonetary terms as well. On the cost side there would be the decline in water quality during the period of water shortage, with its adverse effect on taste, odor, and recreational usability.

---

[2] This is a rough estimate. In any one region a reduction of storage capacity by one-third would result in savings that exceed one-third since marginal costs of storage exceed average costs.

(Some of these nonmonetary costs also have monetary aspects.) The nonmonetary benefits of accepting the risk of water shortage would consist of those that stem from maintaining the natural regimen of the river and which are lost when dams and reservoirs are built—the flooding of rapids and other scenic areas, reduced quantity of natural bottomland vegetation and wildlife, and displacement of people who resent the need for moving.

As can be inferred from the recital of pros and cons, a "scientific" decision cannot be made with the data at hand. It should also be noted that even if the storage is designed to assure flow "100 percent of the time," some uncertainty is still involved, originating from the fact that historical data on the basis of which probability computations have been made are, in some instances, of relatively short duration. The reference to "100 percent of the time" is limited to the range of experience of which we have knowledge. There is a likelihood that in certain regions, time will prove that droughts or floods beyond the limits already known will be encountered.

○